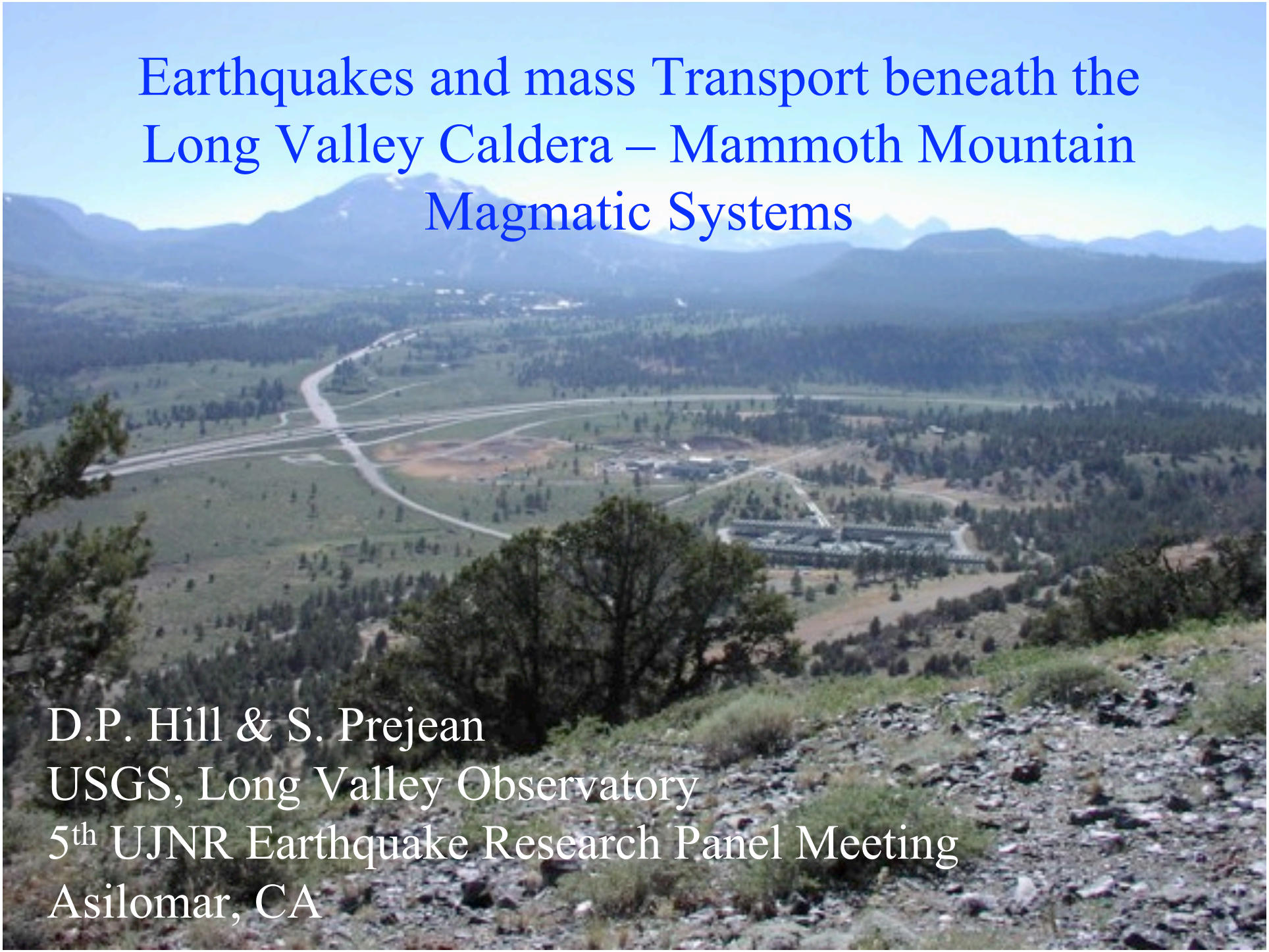
Earthquakes and mass Transport beneath the Long Valley Caldera – Mammoth Mountain Magmatic Systems



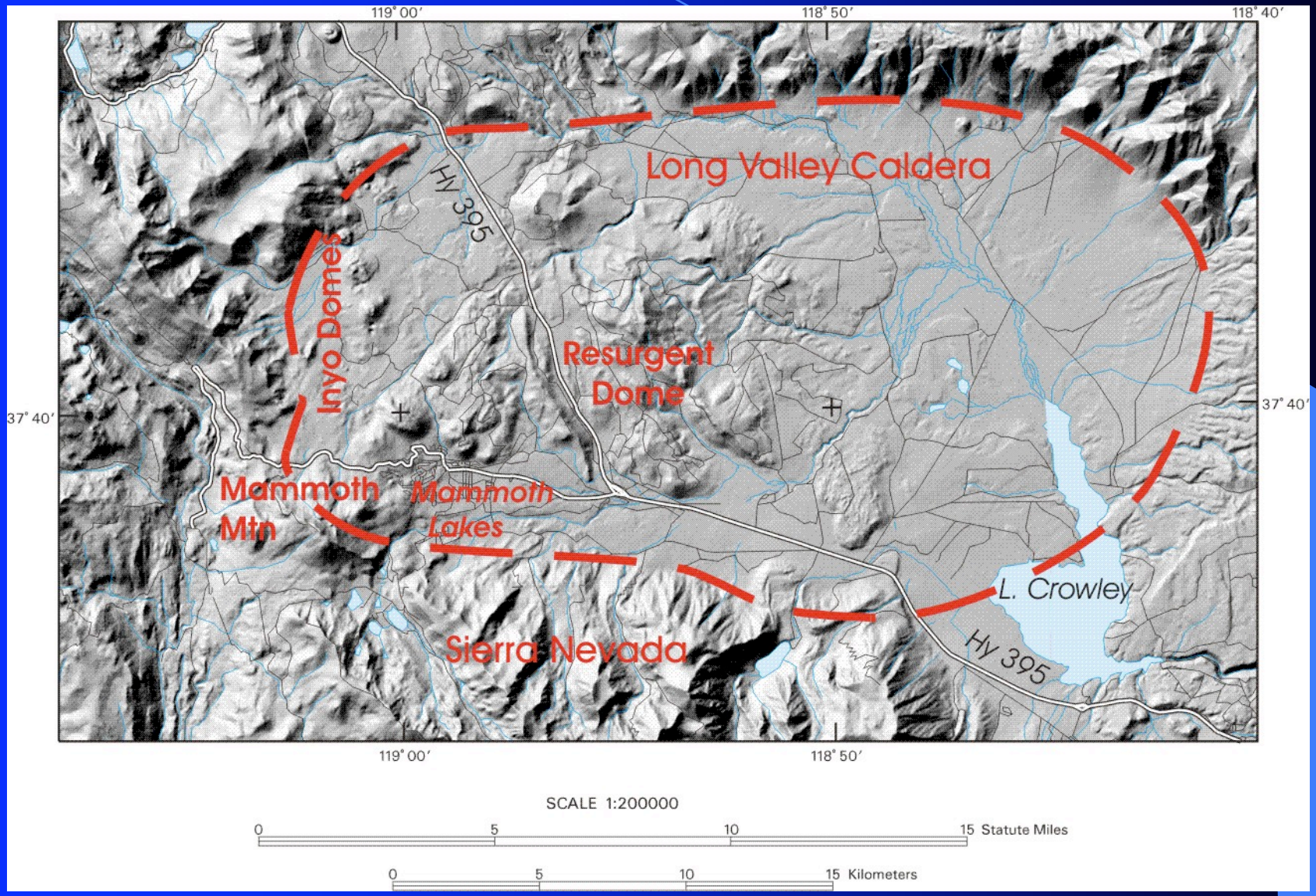
D.P. Hill & S. Prejean
USGS, Long Valley Observatory
5th UJNR Earthquake Research Panel Meeting
Asilomar, CA

Long Valley Caldera

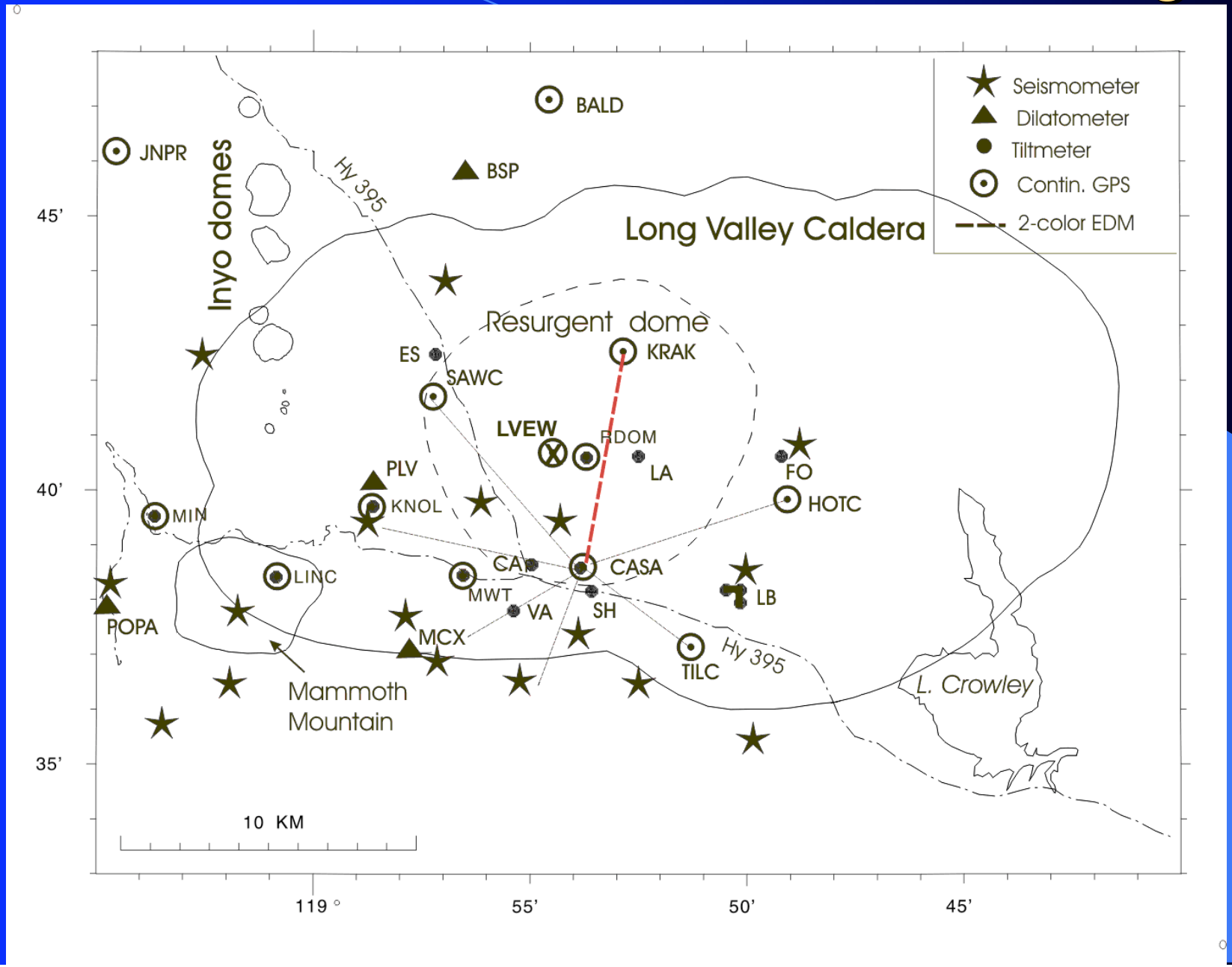
Tectonic setting:

Western margin of a continental rift zone (the Basin & Range extensional province).

Mammoth Lakes: between a volcano and a caldera



Seismic and deformation monitoring



Long Valley Caldera Mono Lake region

3.0 < M < 6.5 earthquakes: 1978-1999

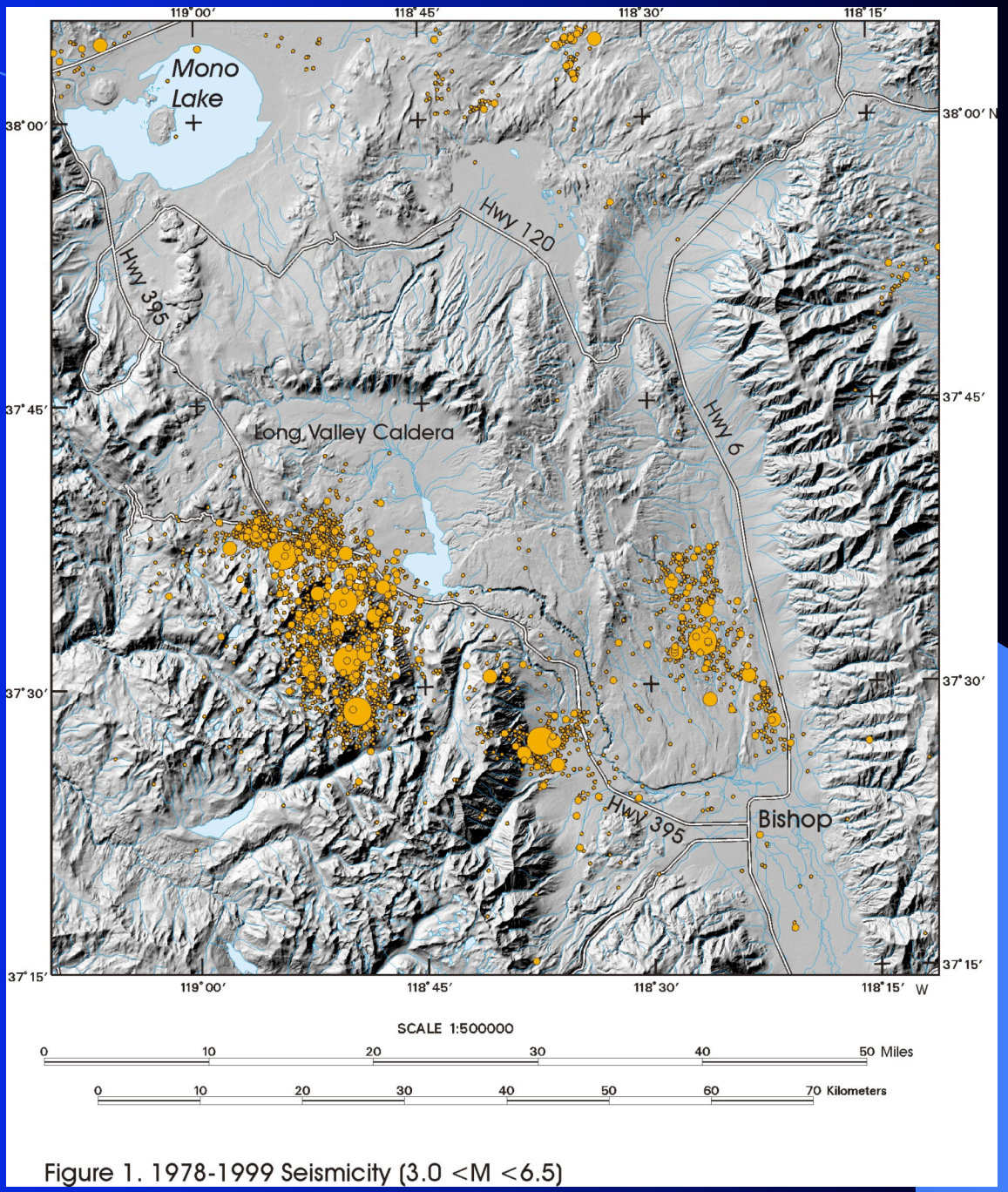
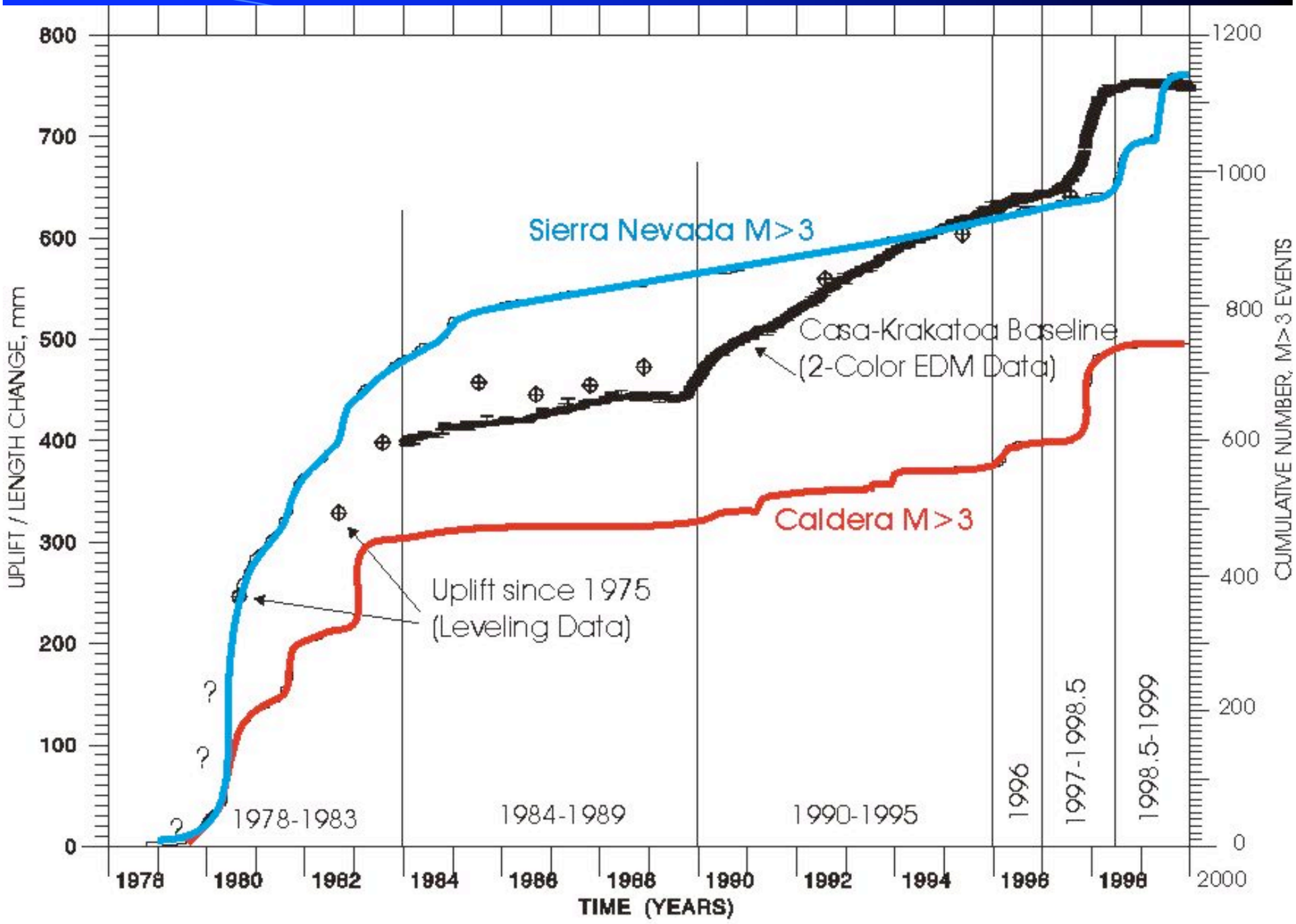
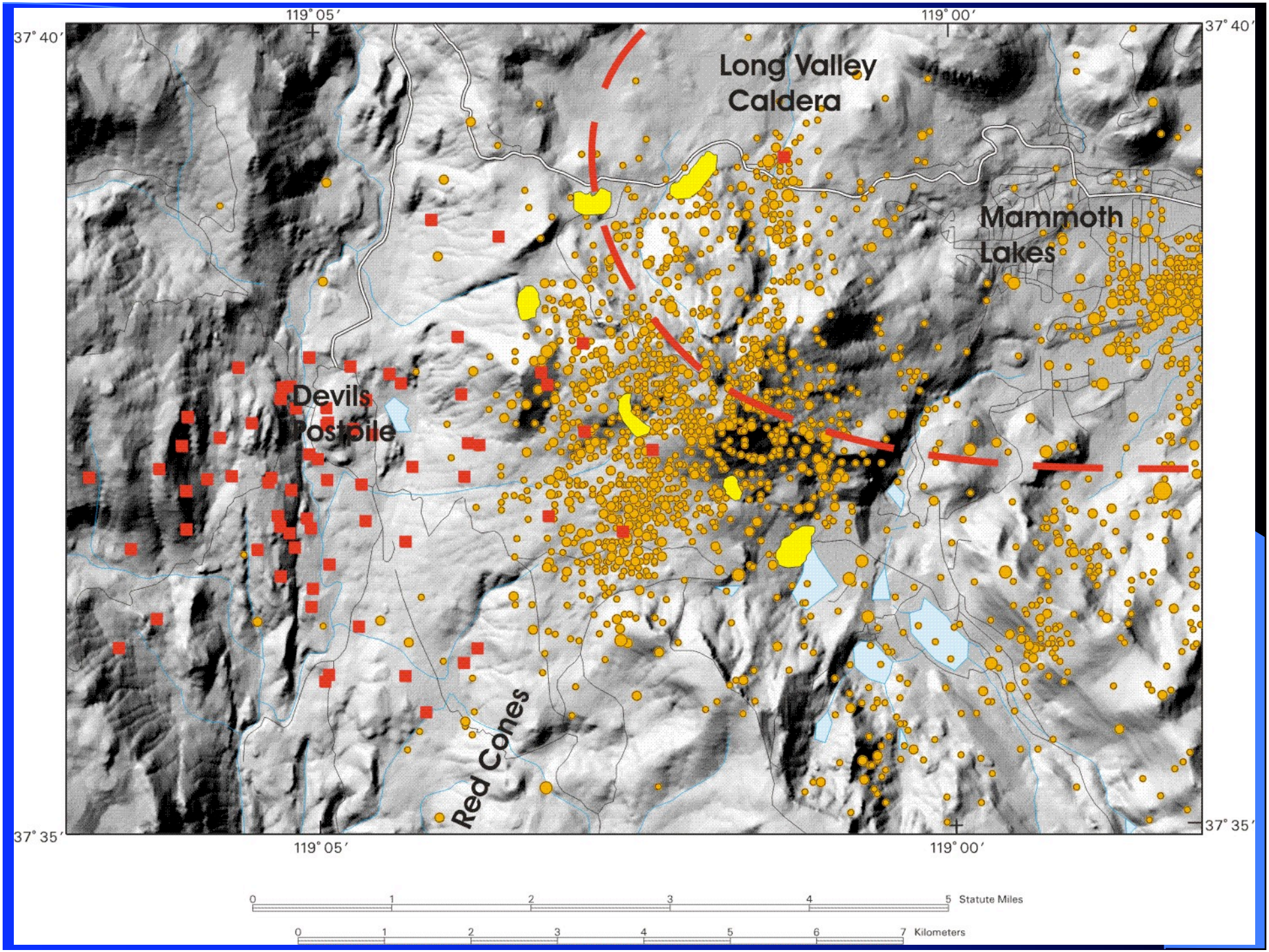
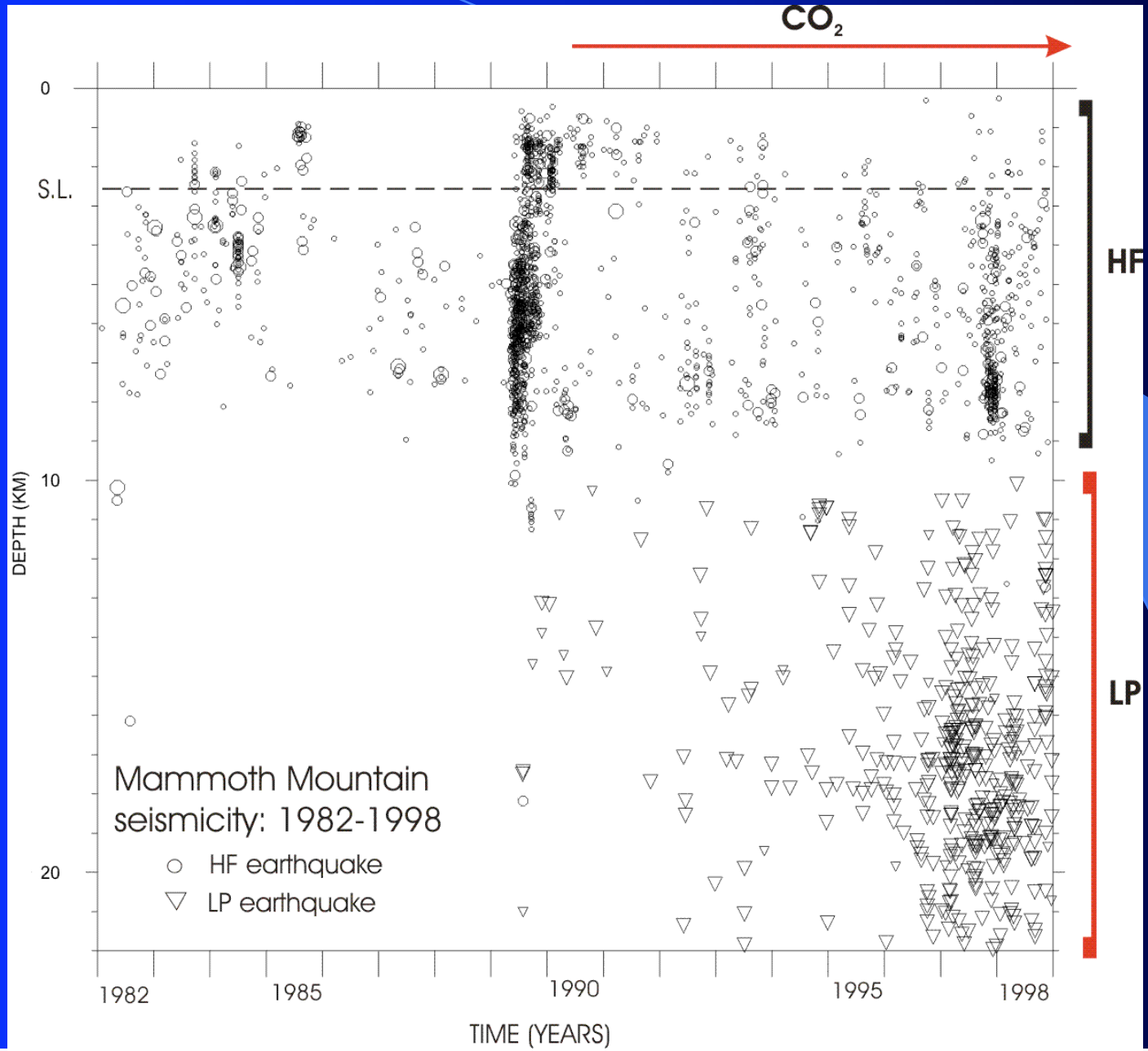


Figure 1. 1978-1999 Seismicity (3.0 <M <6.5)


Sierra Nevada M>3
Casa-Krakatoa Baseline
(2-Color EDM Data)
Caldera M>3
Uplift since 1975
(Leveling Data)
1978-1983
1984-1989
1990-1995
1996
1997-1998.5
1998.5-1999
UPLIFT / LENGTH CHANGE, mm
CUMULATIVE NUMBER, M>3 EVENTS
TIME (YEARS)
0
100
200
300
400
500
600
700
800
0
200
400
600
800
1000
1200
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000


119° 05′
119° 00′
37° 40′
37° 35′
Long Valley
Caldera
Mammoth
Lakes
Devils
Postpile
Red Cones
0 1 2 3 4 5 Statute Miles
0 1 2 3 4 5 6 7 Kilometers

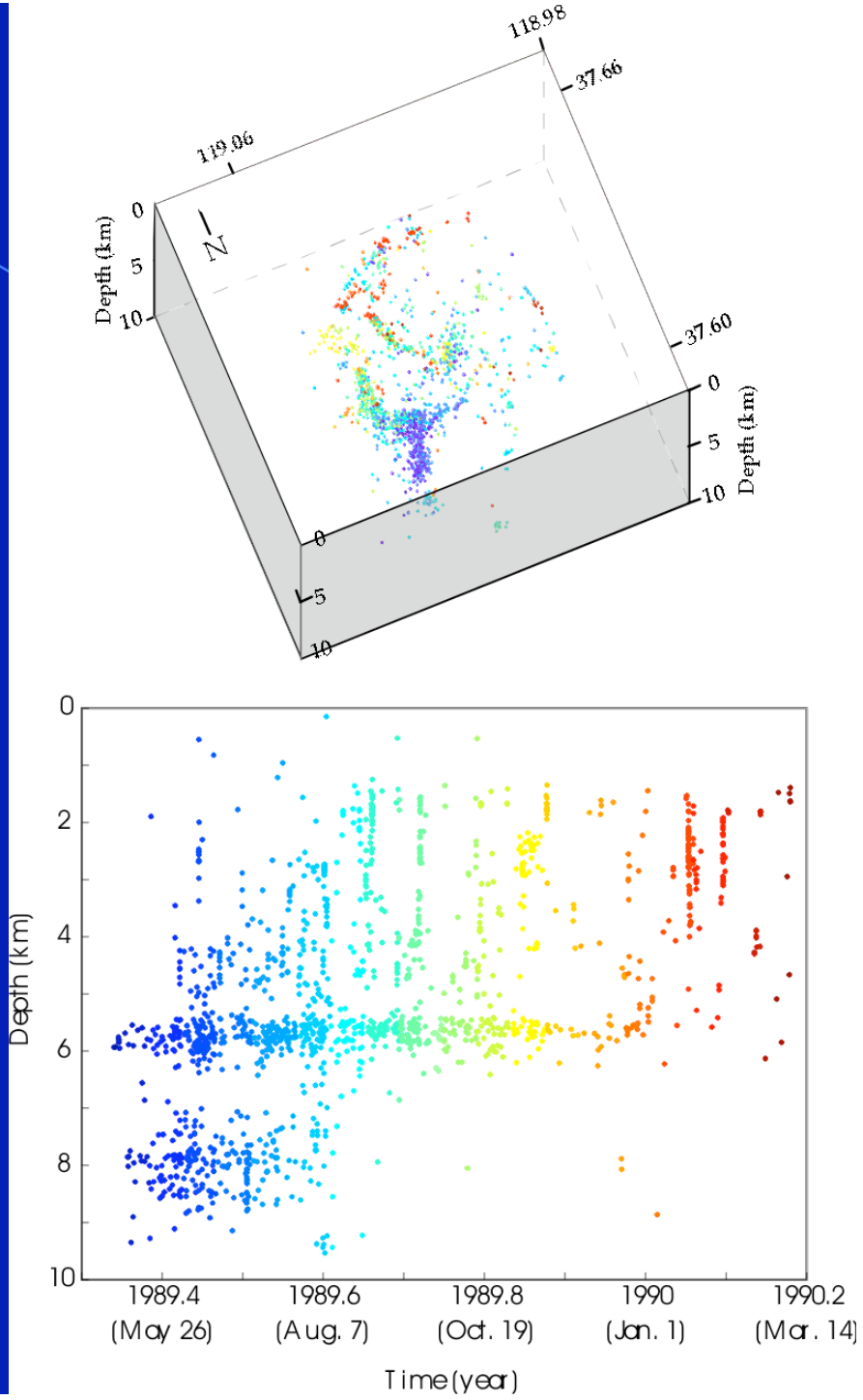
Mammoth Mtn earthquakes: 1982-98



1989 Mammoth Mountain swarm with high-resolution hypocenters

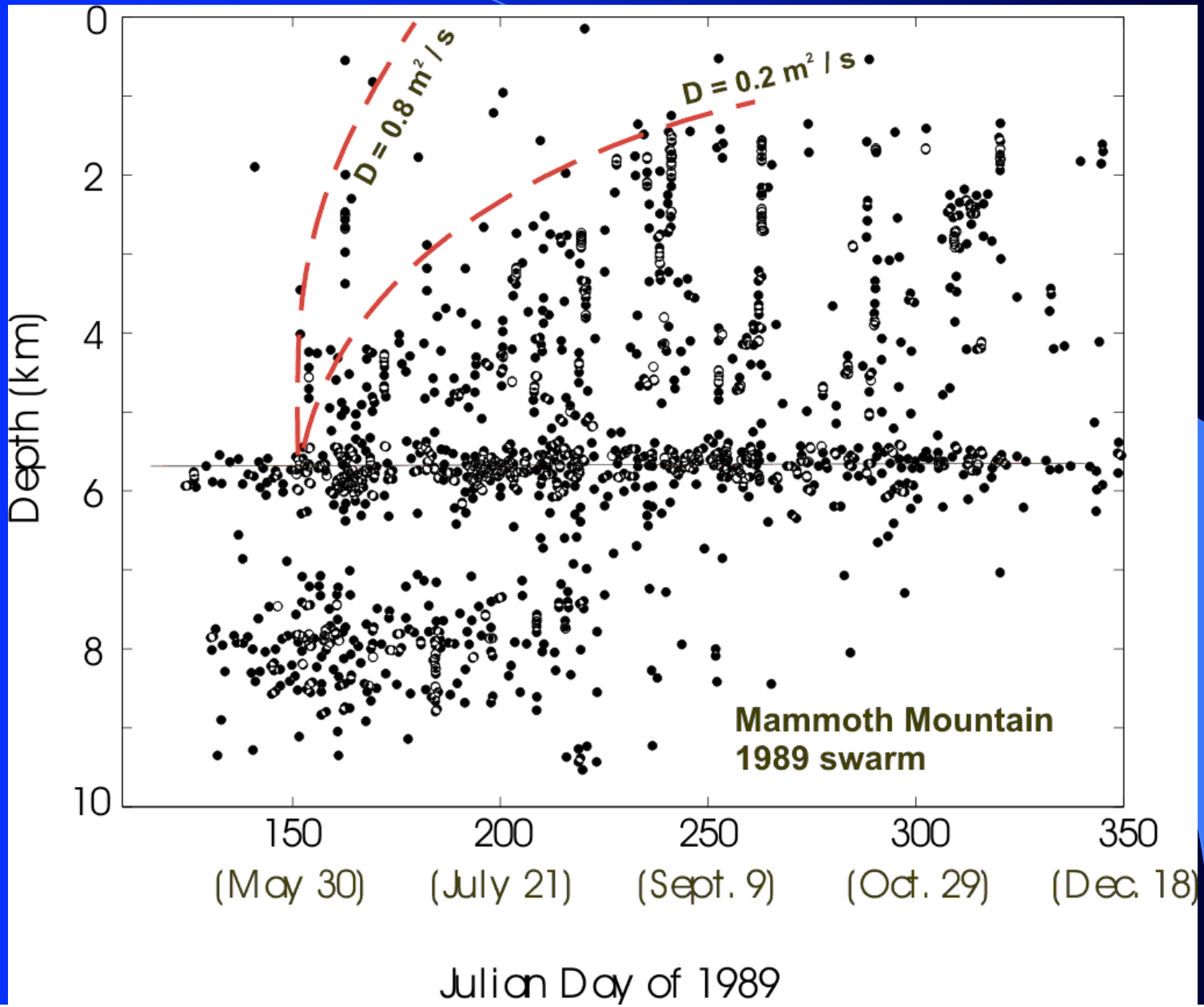
color coded with increasing time from blue through red

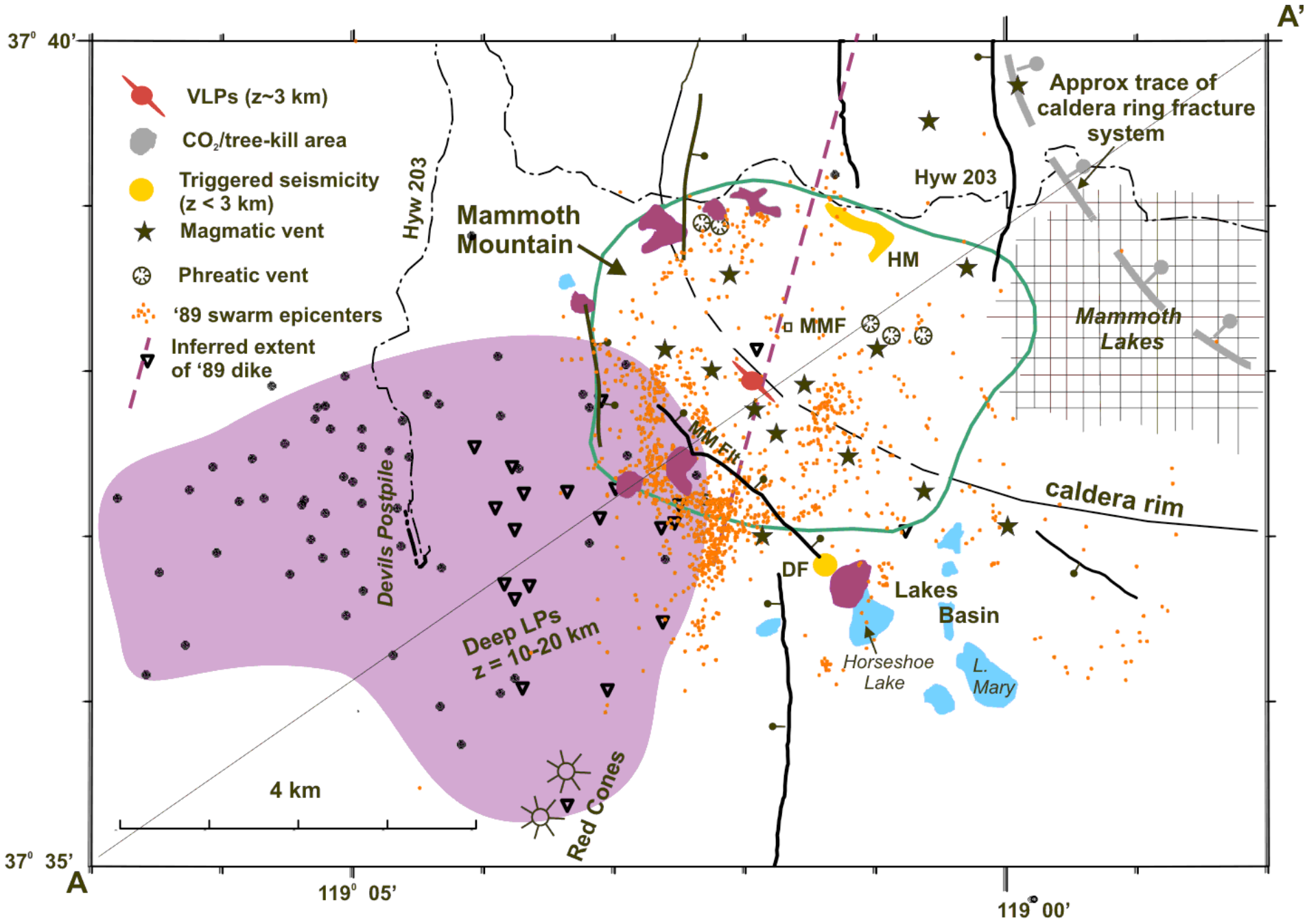
from S. Prejean



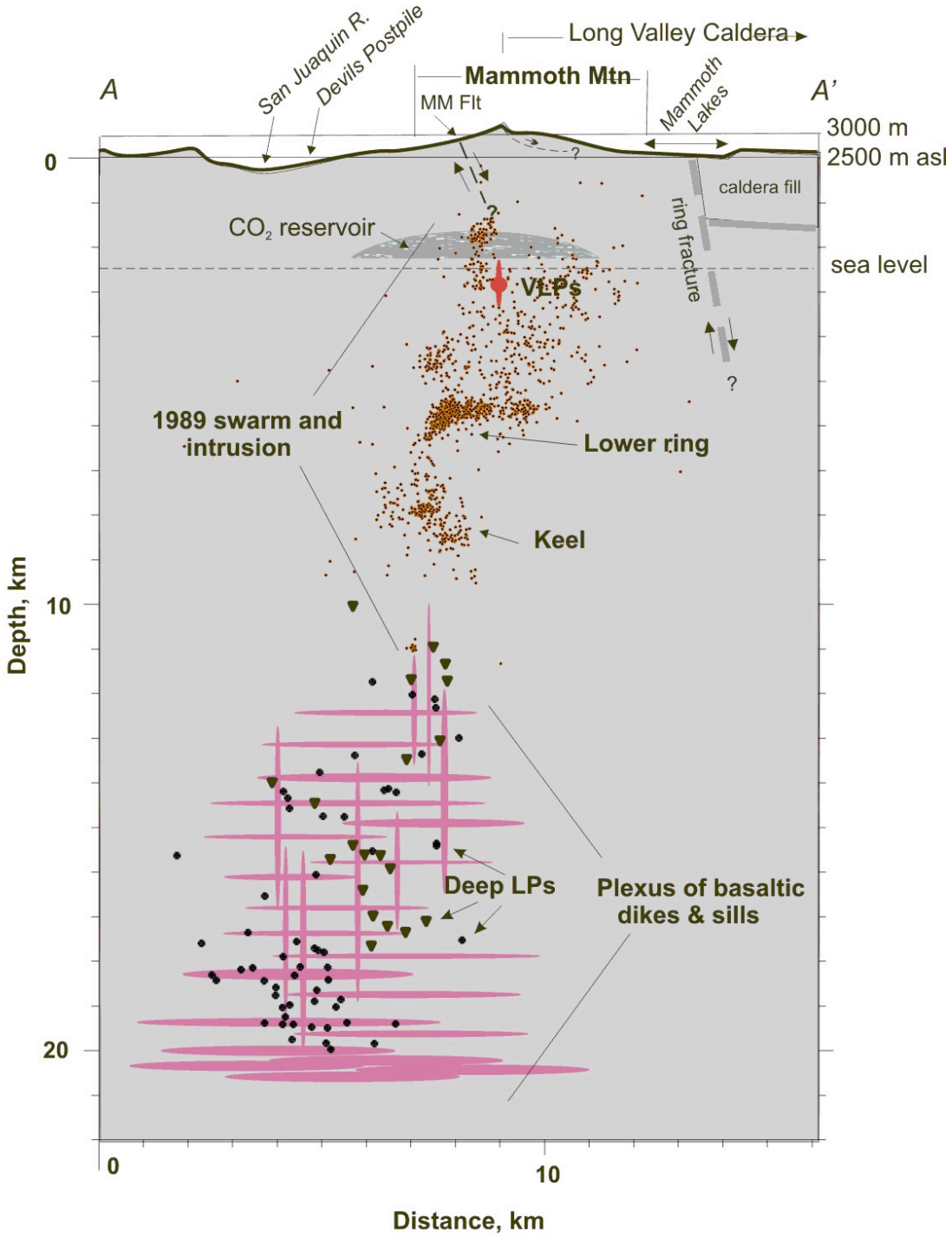
Seismicity propagation and hydraulic diffusivity

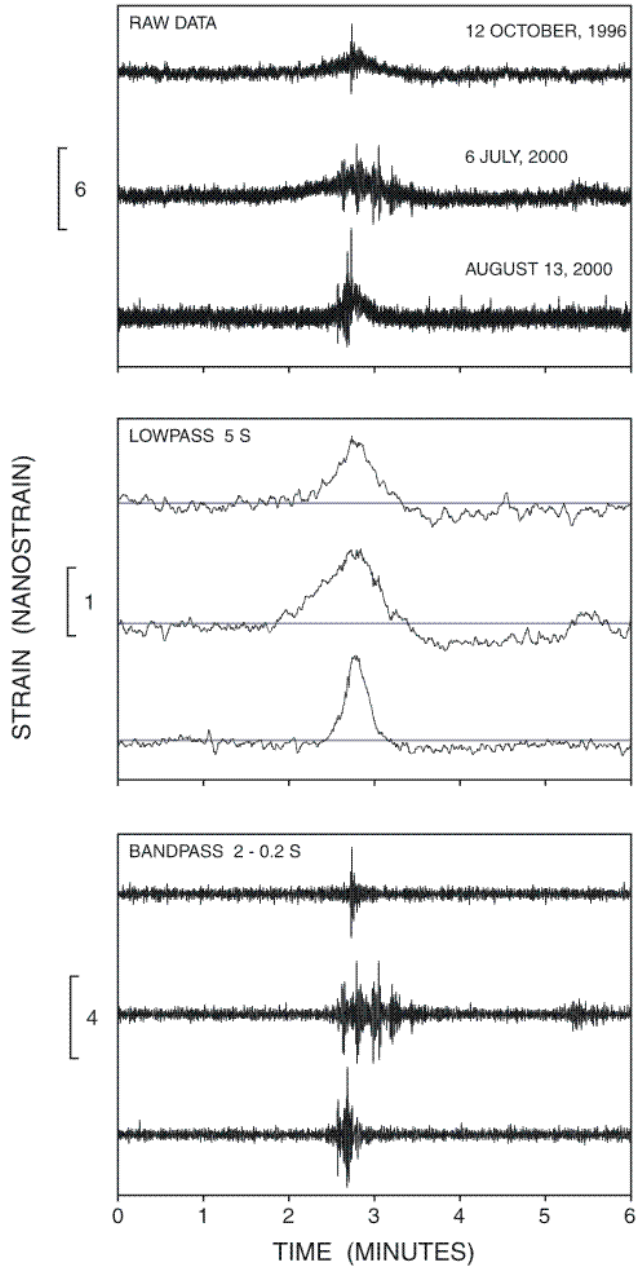
$$D = r^2 / (4\pi t)$$

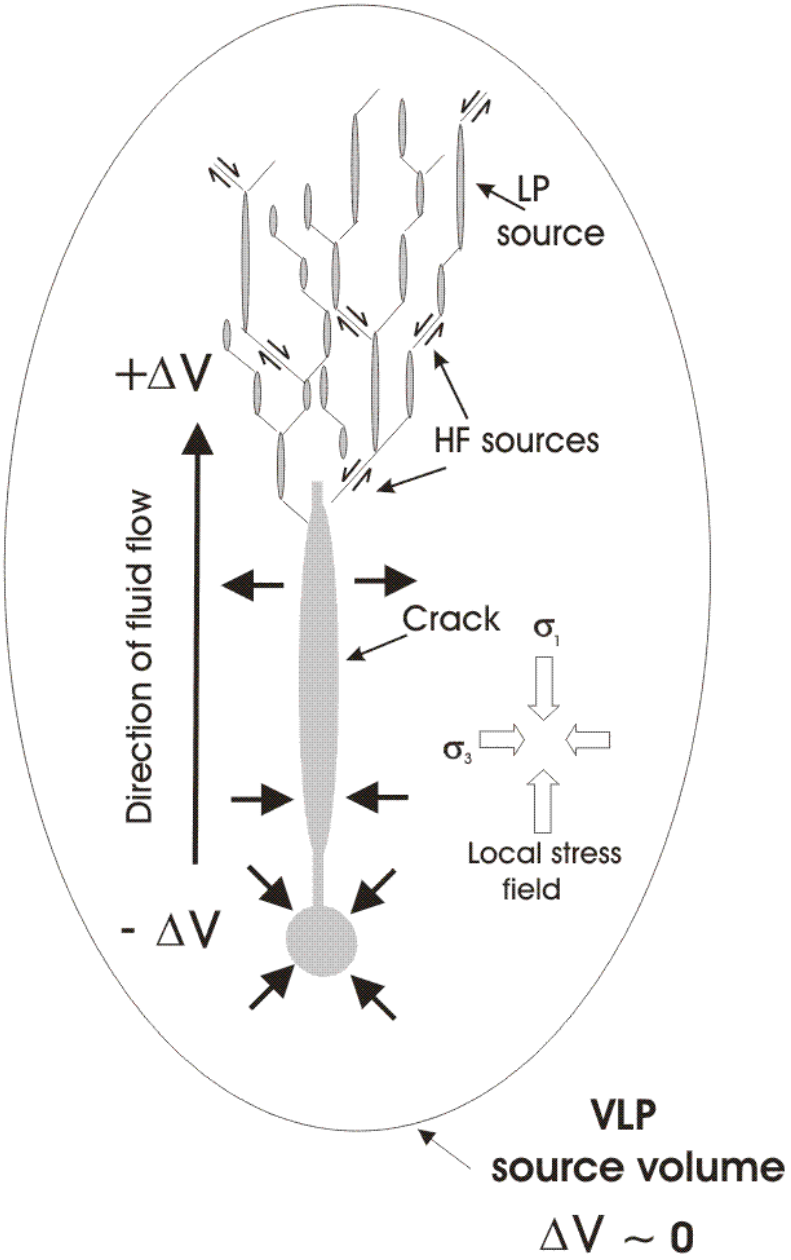



A'
37° 40'
VLPs (z~3 km)
CO2/tree-kill area
Triggered seismicity (z < 3 km)
Magmatic vent
Phreatic vent
'89 swarm epicenters
Inferred extent of '89 dike
Hyw 203
Mammoth Mountain
Hyw 203
Approx trace of caldera ring fracture system
HM
MMF
Mammoth Lakes
MM Flt
caldera rim
Devils Postpile
Deep LPs z = 10-20 km
DF
Lakes Basin
Horseshoe Lake
L. Mary
4 km
Red Cones
37° 35'
A
119° 05'
119° 00'

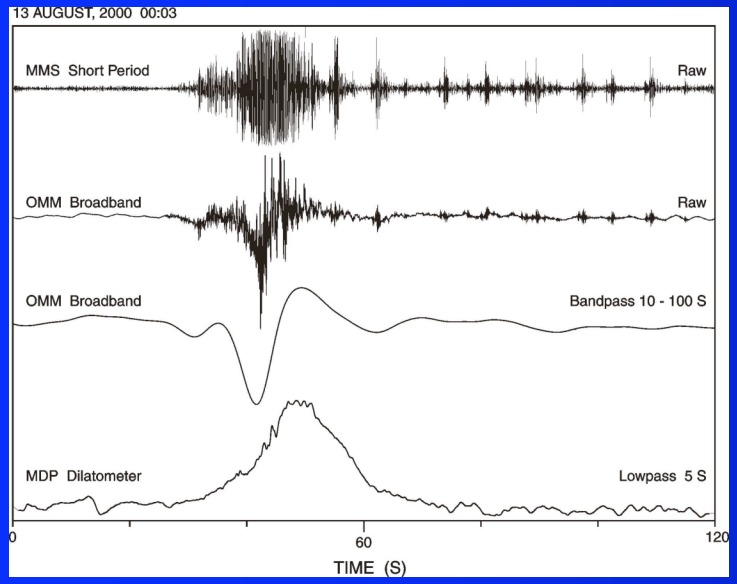
Mammoth Mountain cross-section A-A’ view to NW



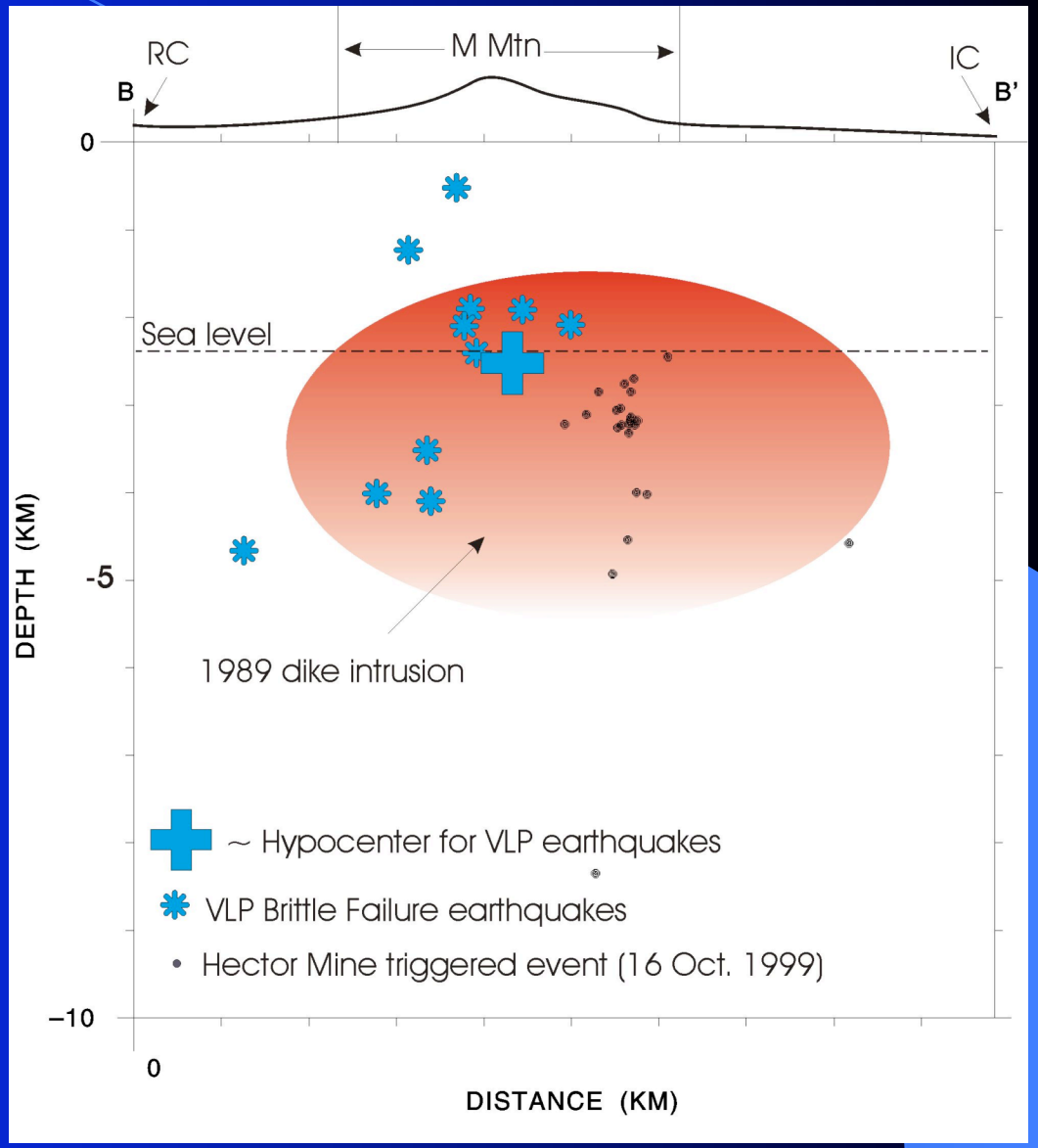

RAW DATA
12 OCTOBER, 1996
6 JULY, 2000
AUGUST 13, 2000
6
LOWPASS 5 S
1
BANDPASS 2 - 0.2 S
4
STRAIN (NANOSTRAIN)
0
1
2
3
4
5
6
TIME (MINUTES)


LP
source
+ΔV
HF sources
Direction of fluid flow
Crack
σ1
σ3
Local stress
field
- ΔV
VLP
source volume
ΔV ~ 0

Mammoth Mountain VLP earthquakes

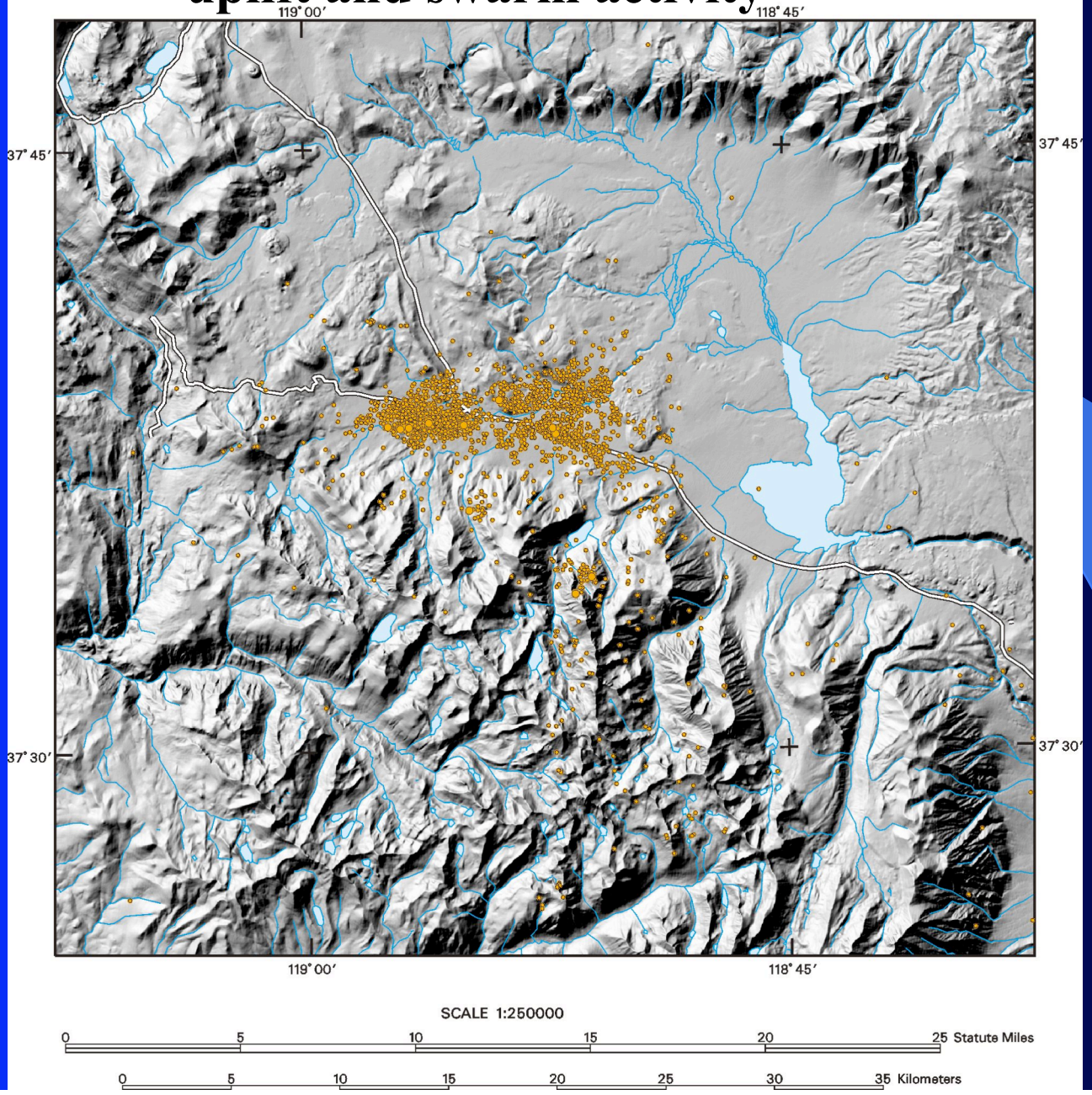


13 August 2000
VLP earthquake

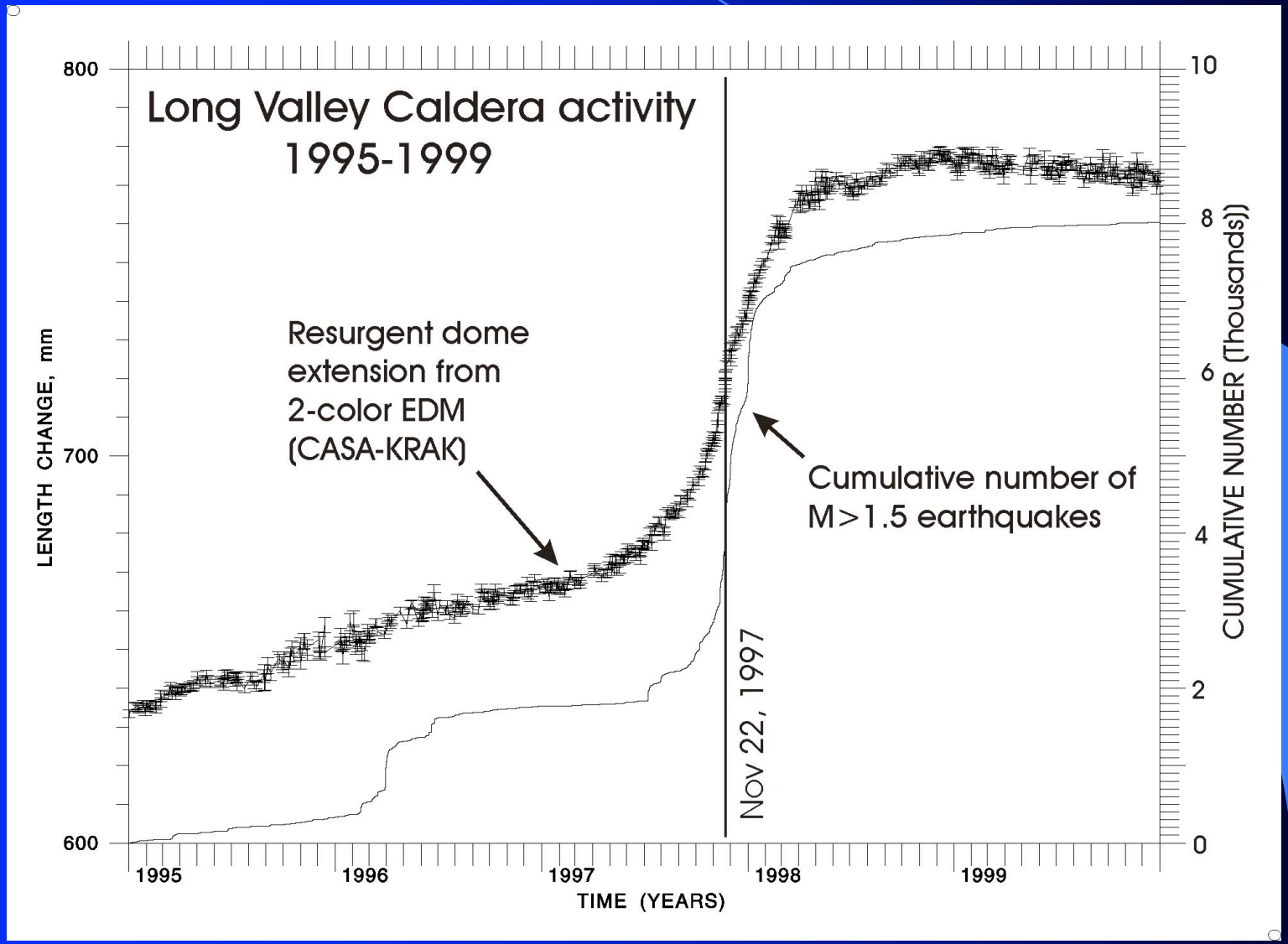


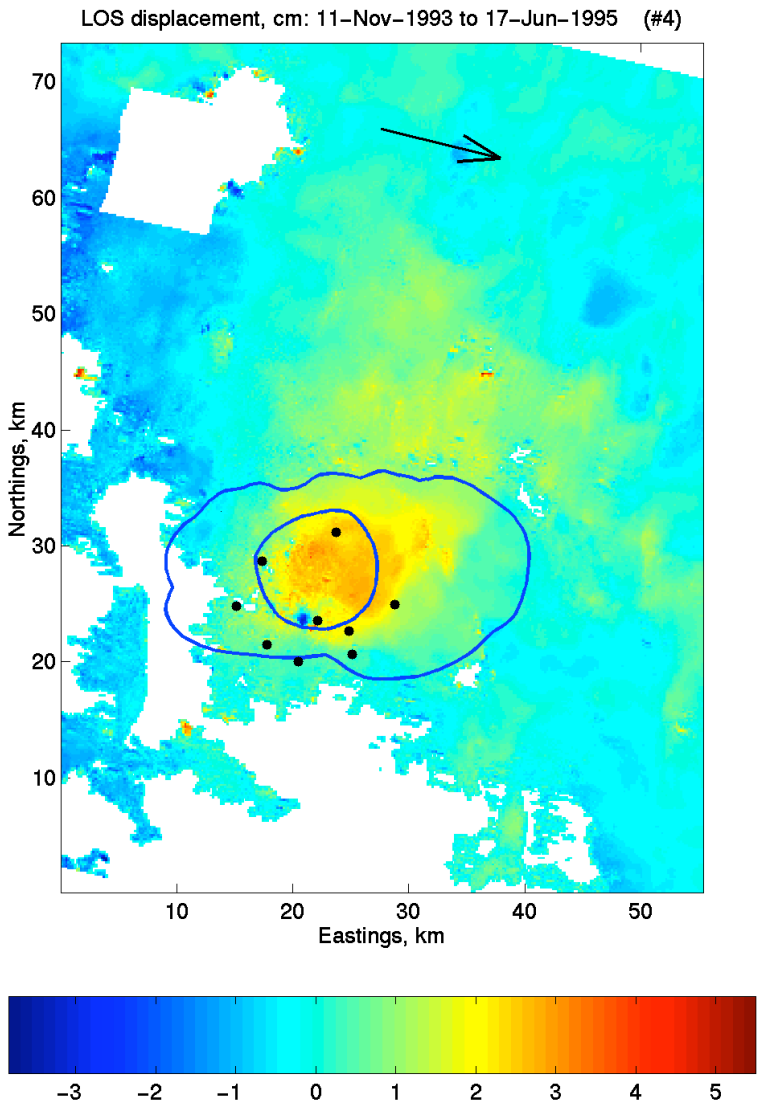
LVC M>2 Seismiciy 1997-1998.5

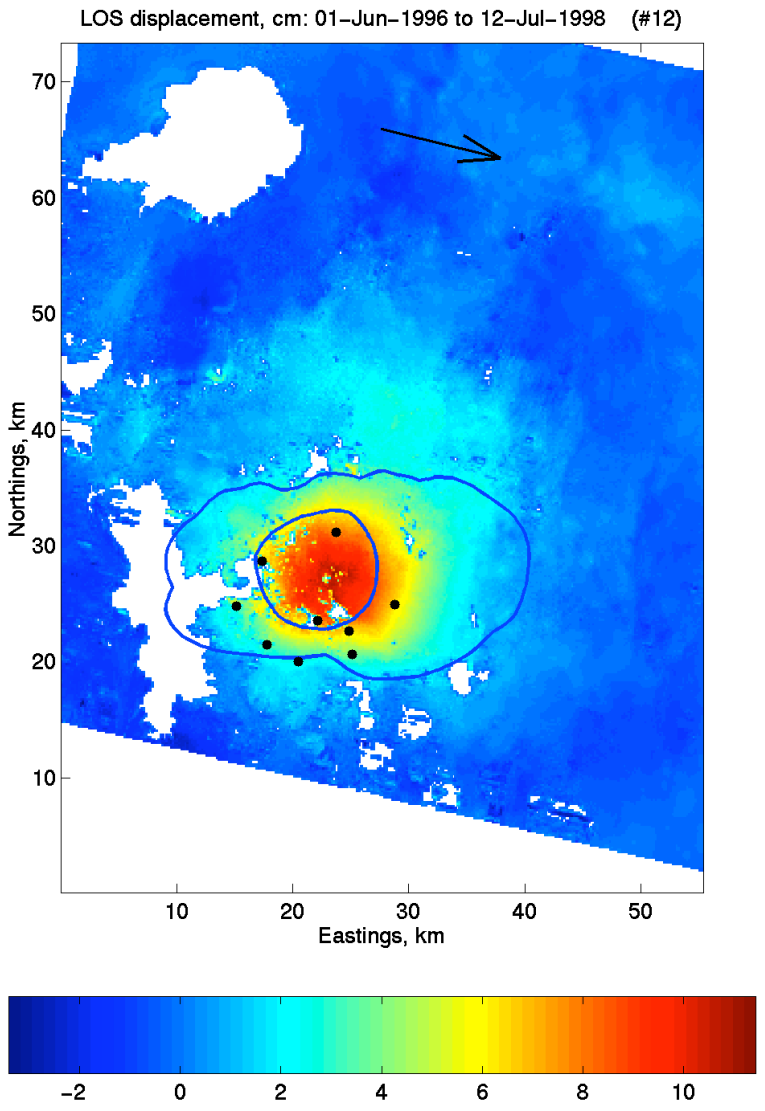
The 1997-98 Unrest episode: accelerating uplift and swarm activity



LVC deformation and seismicity 1995-1999

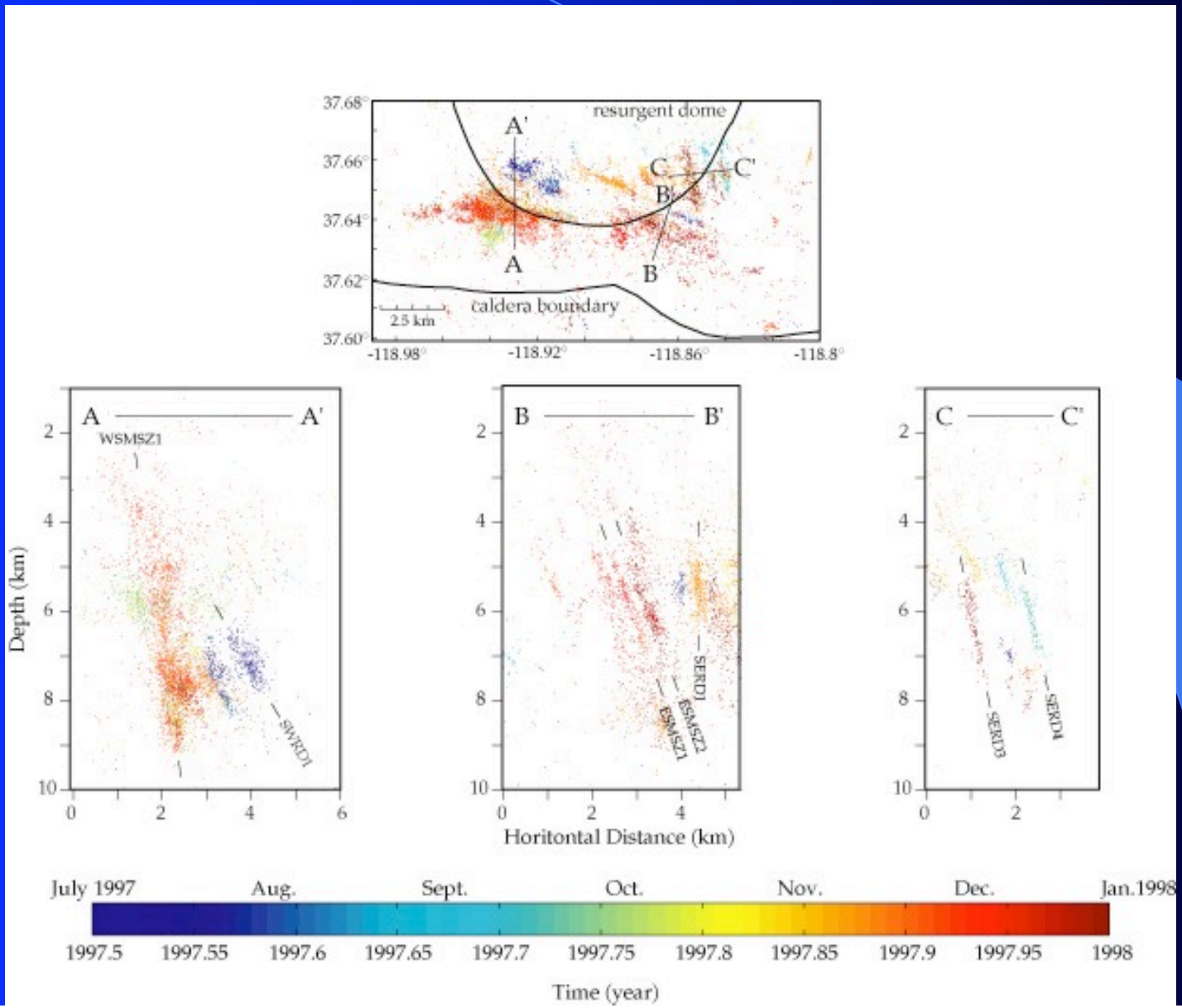






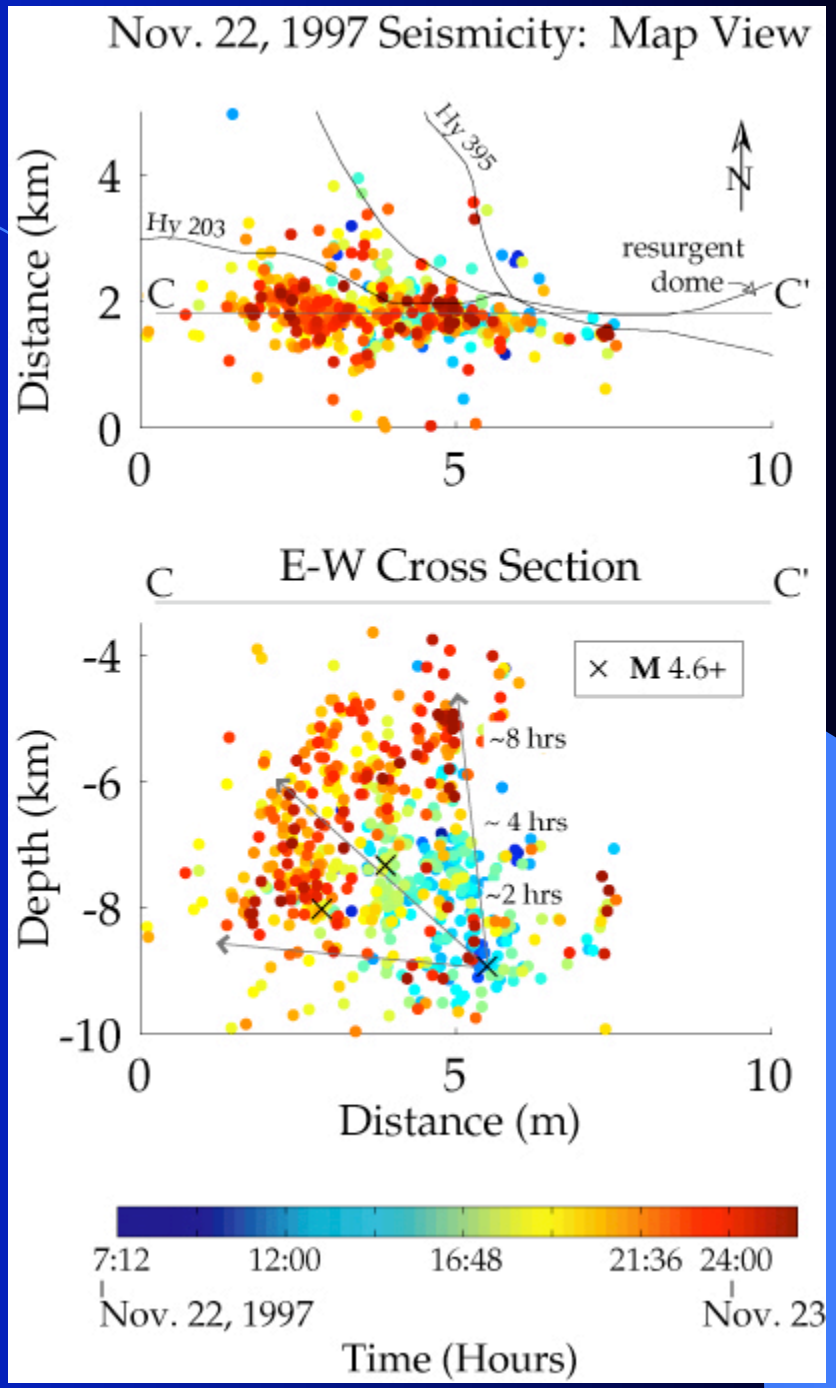
InSAR images of LVC courtesy Mark Simons, Caltech

High-resolution seismicity patterns for the 1997 south moat swarm by the double-difference method (Prejean et al., 2002)



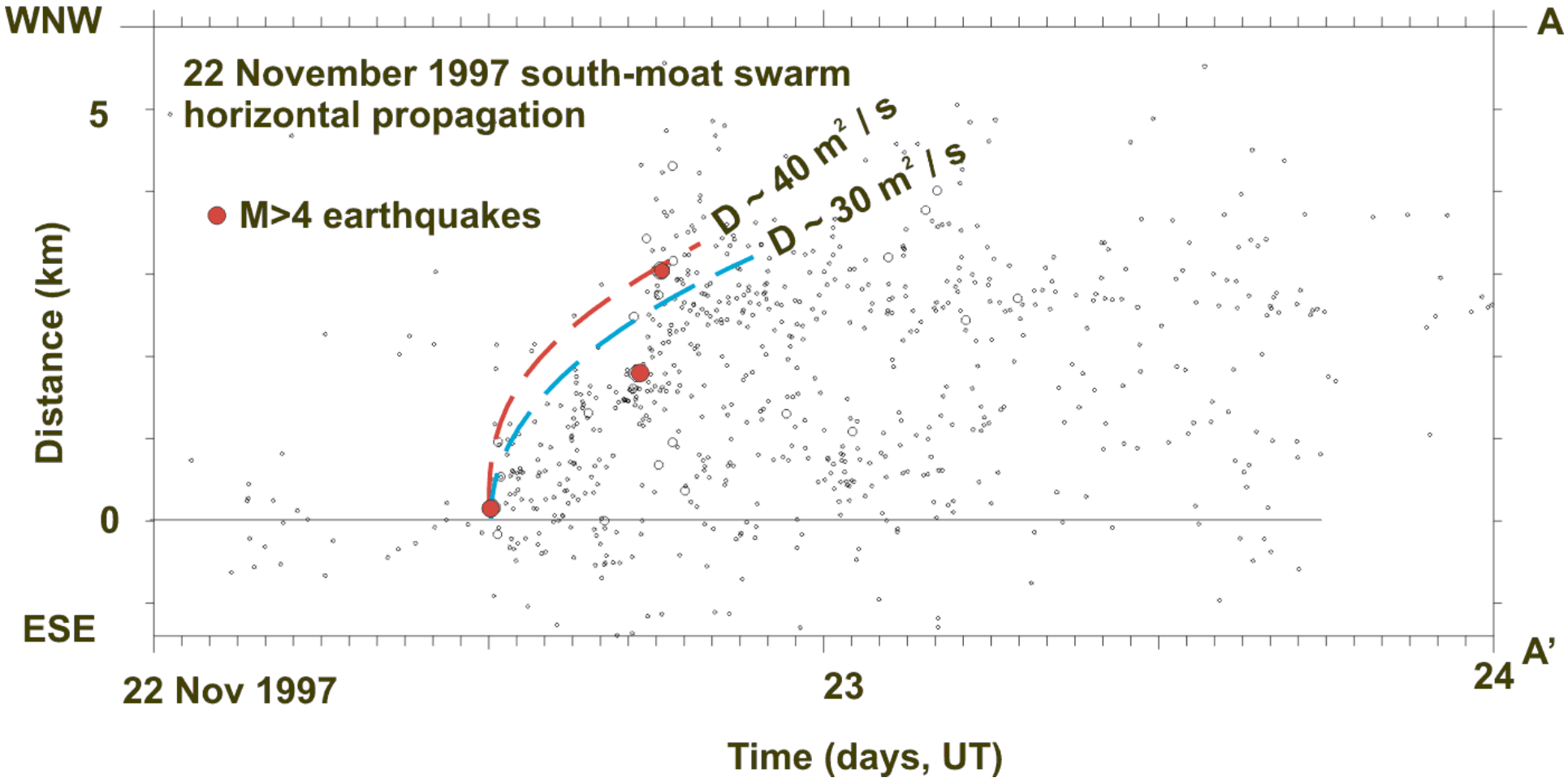
Hypocenter migration during the Nov 22, 1997 peak in south-moat earthquake swarm activity.

From S. Prejean et al., 2002



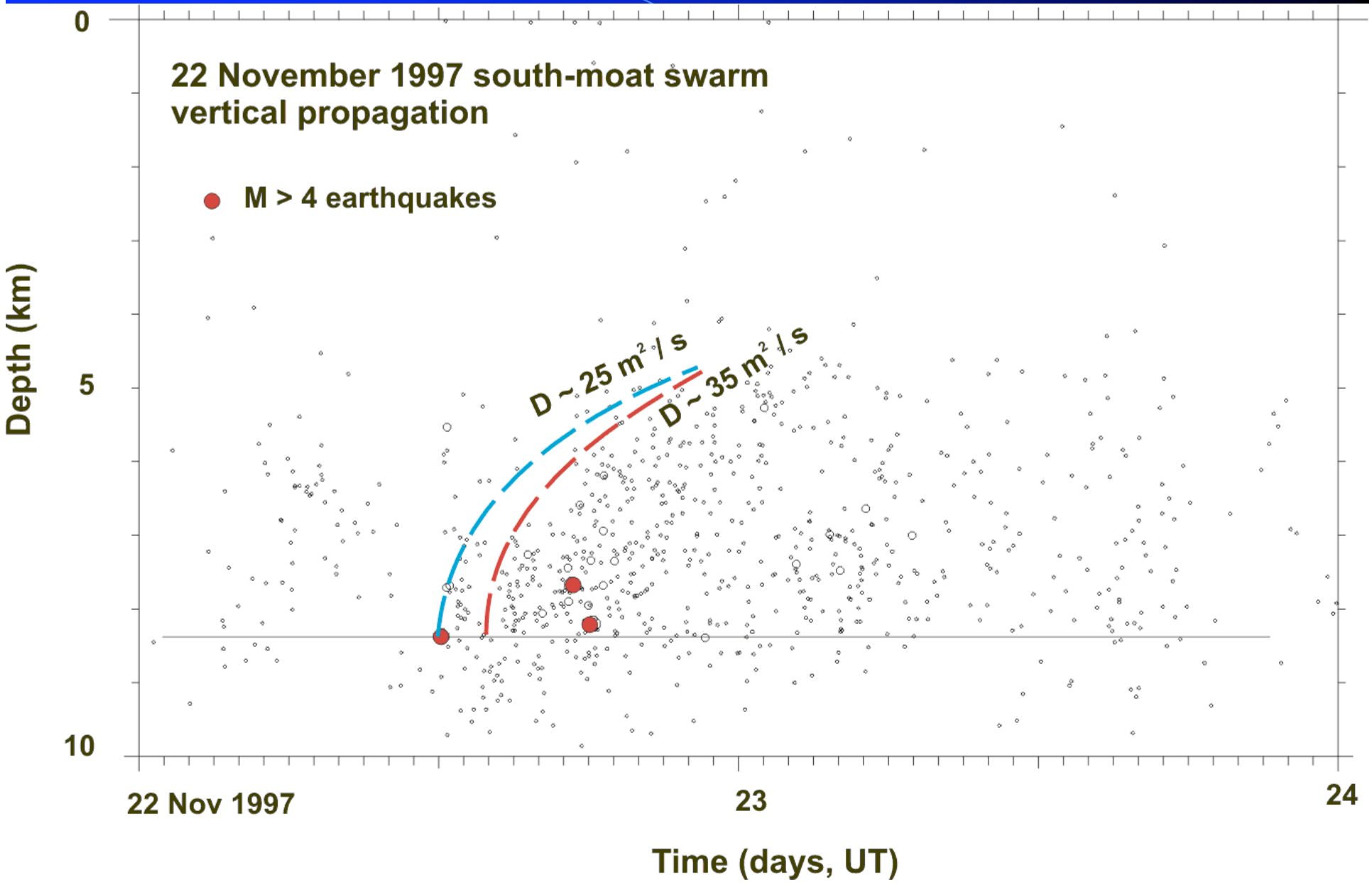
Seismicity propagation and hydraulic diffusivity

$$D = r^2 / (4\pi t)$$



Seismicity propagation and hydraulic diffusivity

$$D = r^2 / (4\pi t)$$



Deformation and hydrologic response to the Nov 22, 1997 south-moat swarm: 11/21 - 11/25

Roeloffs et al. 2003
JVGR

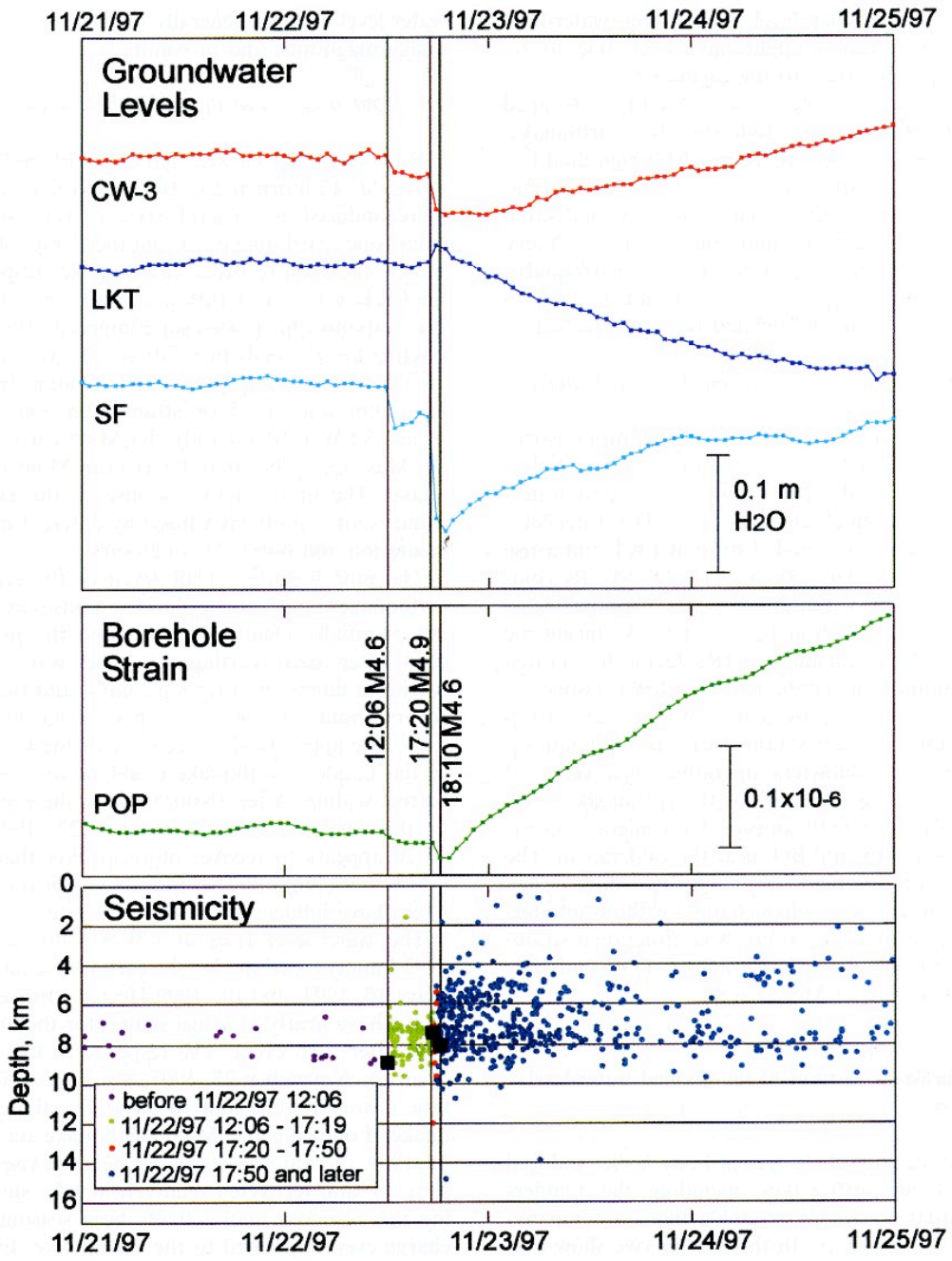
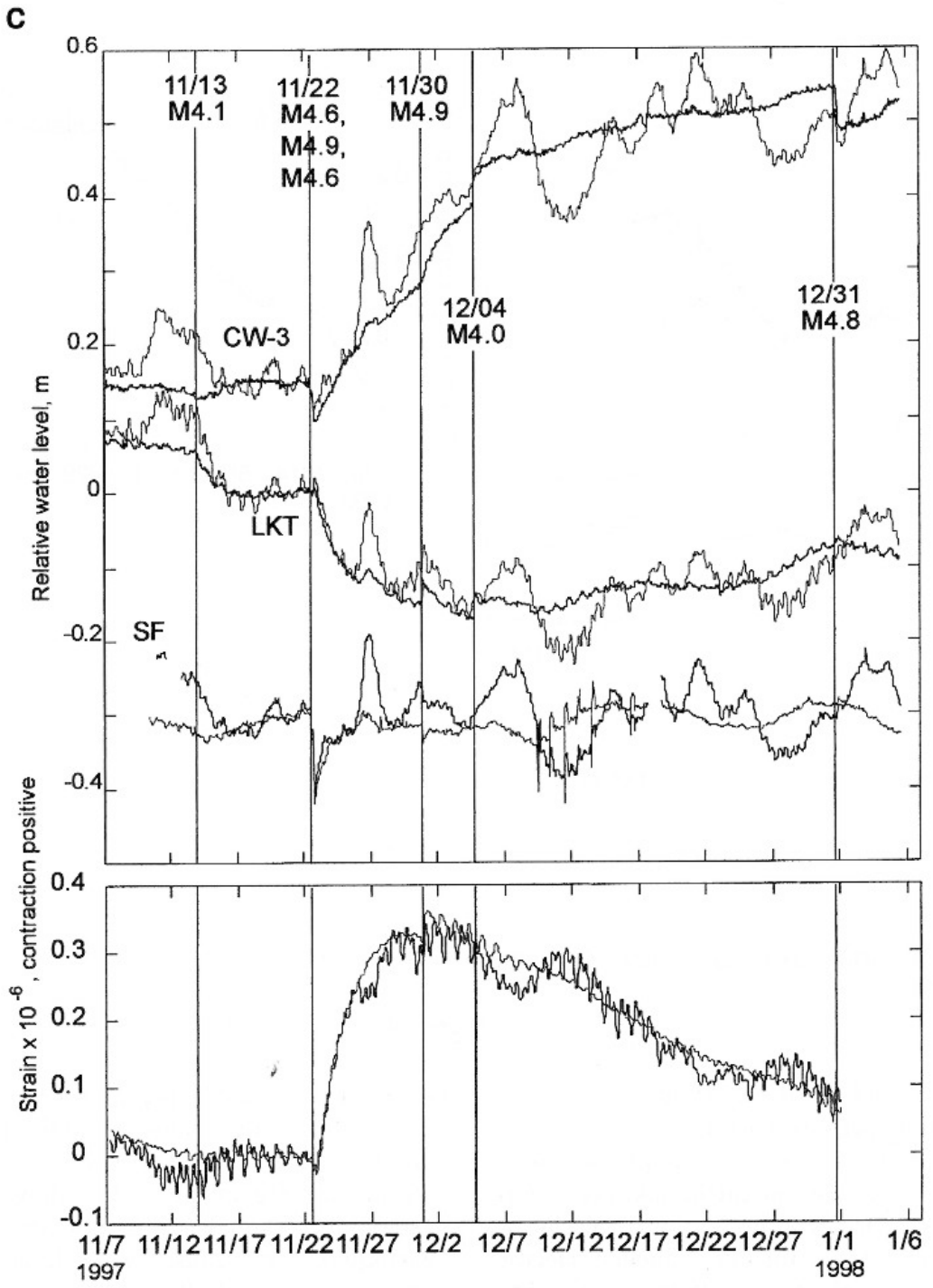


Fig. 8. Water-level and seismicity data for November 21–25, 1997 (relocated hypocenters courtesy of S. Prejean, USGS).

Deformation and hydrologic response to the Nov 22, 1997 south-moat swarm: 11/7/97 - 1/6/98

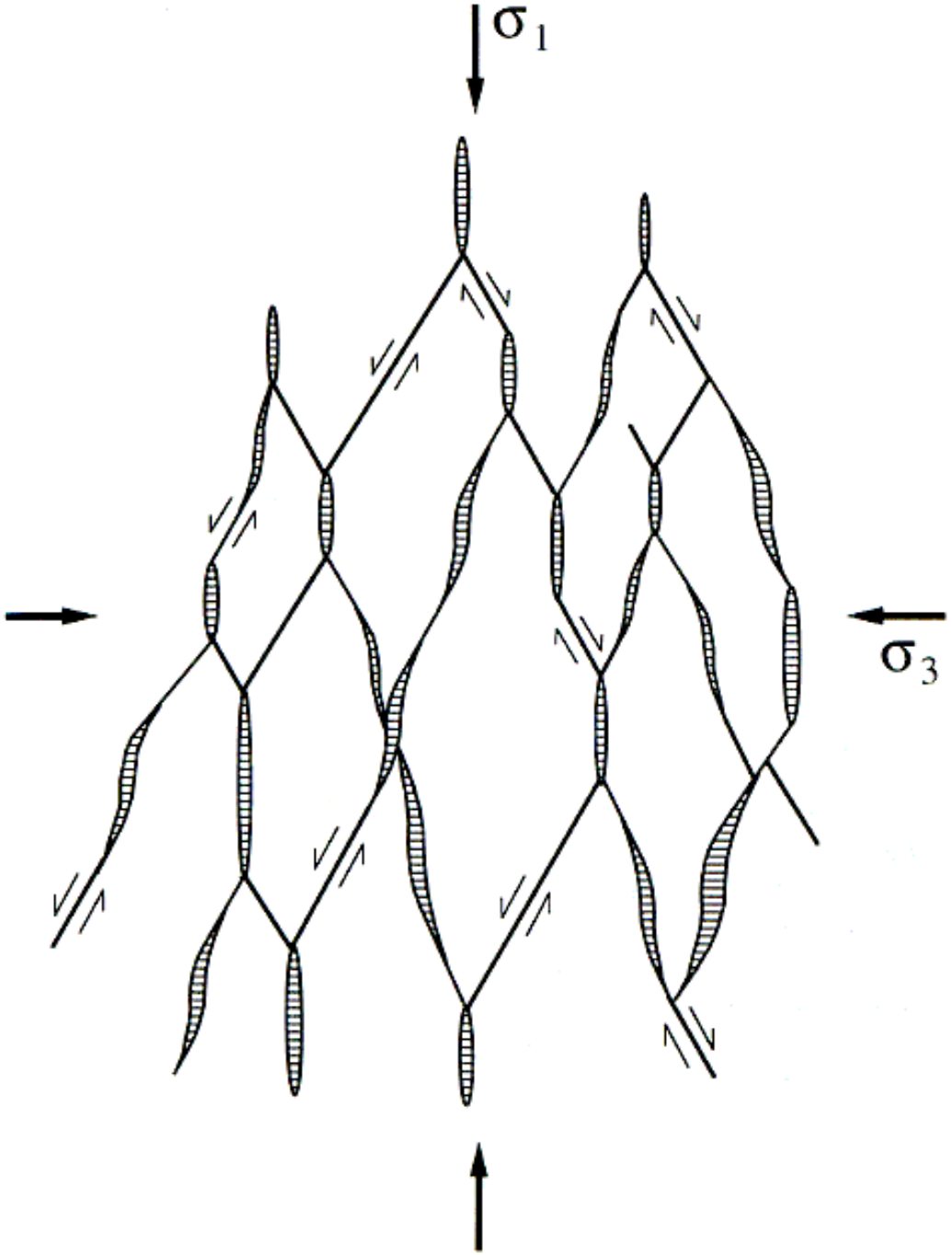


Roeloffs et al. 2003

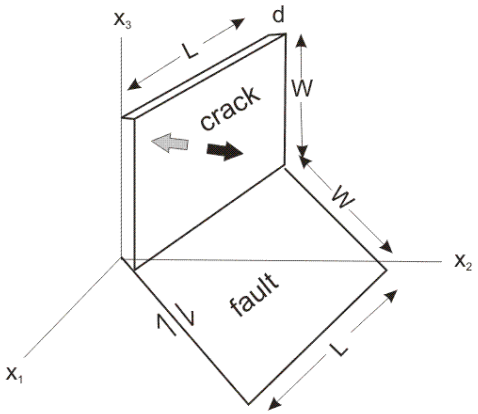
JVGR

Hill-type fracture mesh linking fault slip to fracture opening

Sibson, 1996
J. Structural Geo.



Approximate relation between cumulative seismic moment, Σ Mo, and total crack volume ΔV in an earthquake swarm fracture mesh



displacement, d

Area, A = (WL)

Crack moment, **M**c ~ dA $\begin{bmatrix} \lambda & 0 & 0 \\ 0 & \lambda+2\mu & 0 \\ 0 & 0 & \lambda \end{bmatrix}$, ||**M**c|| = Mc ~ $(\lambda+2\mu)$ dA

Fault moment, **M**f ~ dA $\begin{bmatrix} 0 & 0 & 0 \\ 0 & \mu & 0 \\ 0 & 0 & -\mu \end{bmatrix}$, ||**M**c|| = Mf ~ μdA

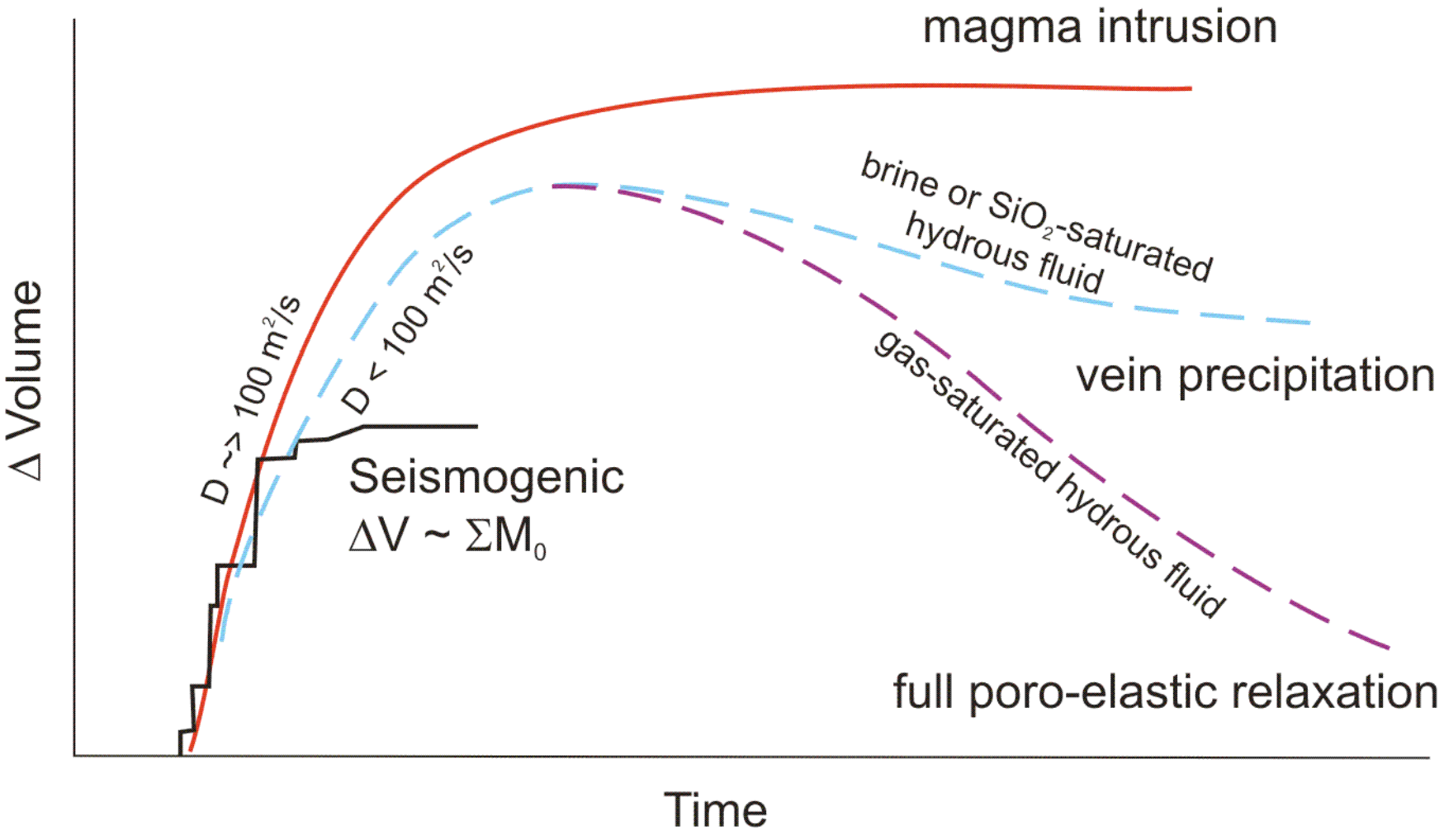
For $\sigma = 1/4$, $\lambda \sim \mu$, and dA ~ ΔV

Mo = Mc + Mf ~ $4\mu\ \Delta V$

$$\Sigma\ \Delta V \sim (1/4\mu)\ \Sigma\ Mo$$

Or, the total volume change is roughly 1/4th the observed cumulative moment – when both the fault and crack radiate in the seismic frequency band

Fluid volume estimates with time from Seismic and Geodetic data



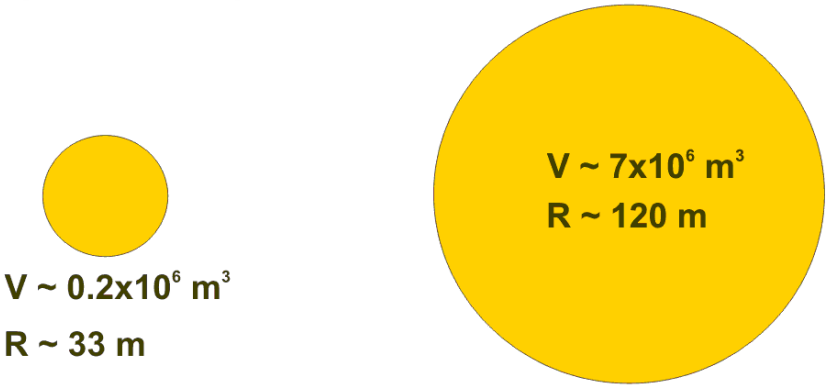
Estimated intrusion volumes:

1989 Mammoth Mtn swarm

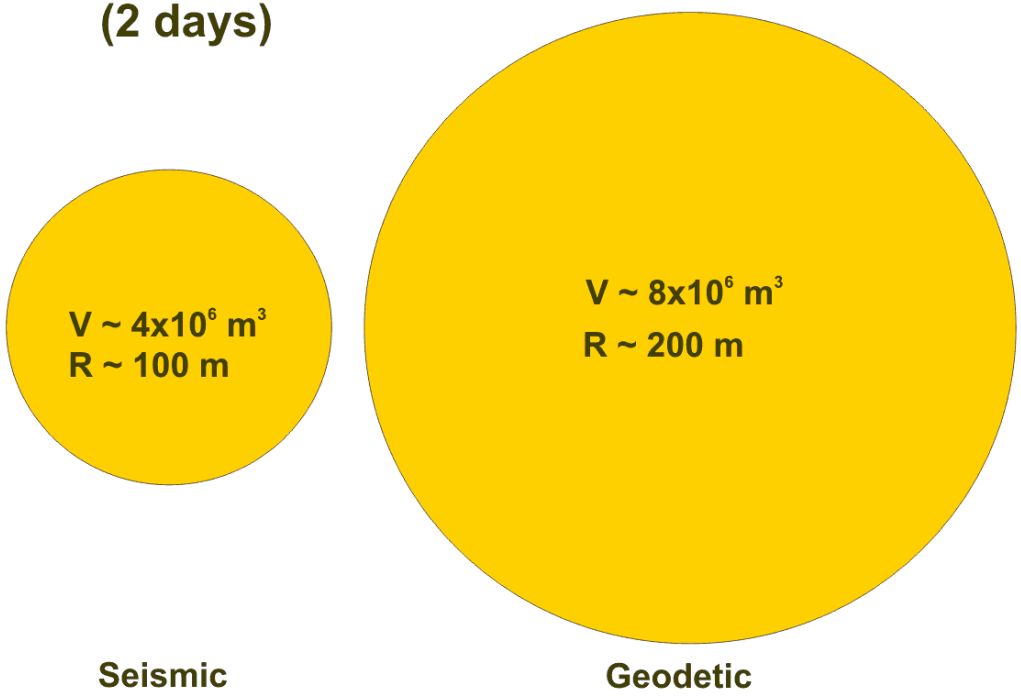
and the

Nov 22 1997 South moat swarm

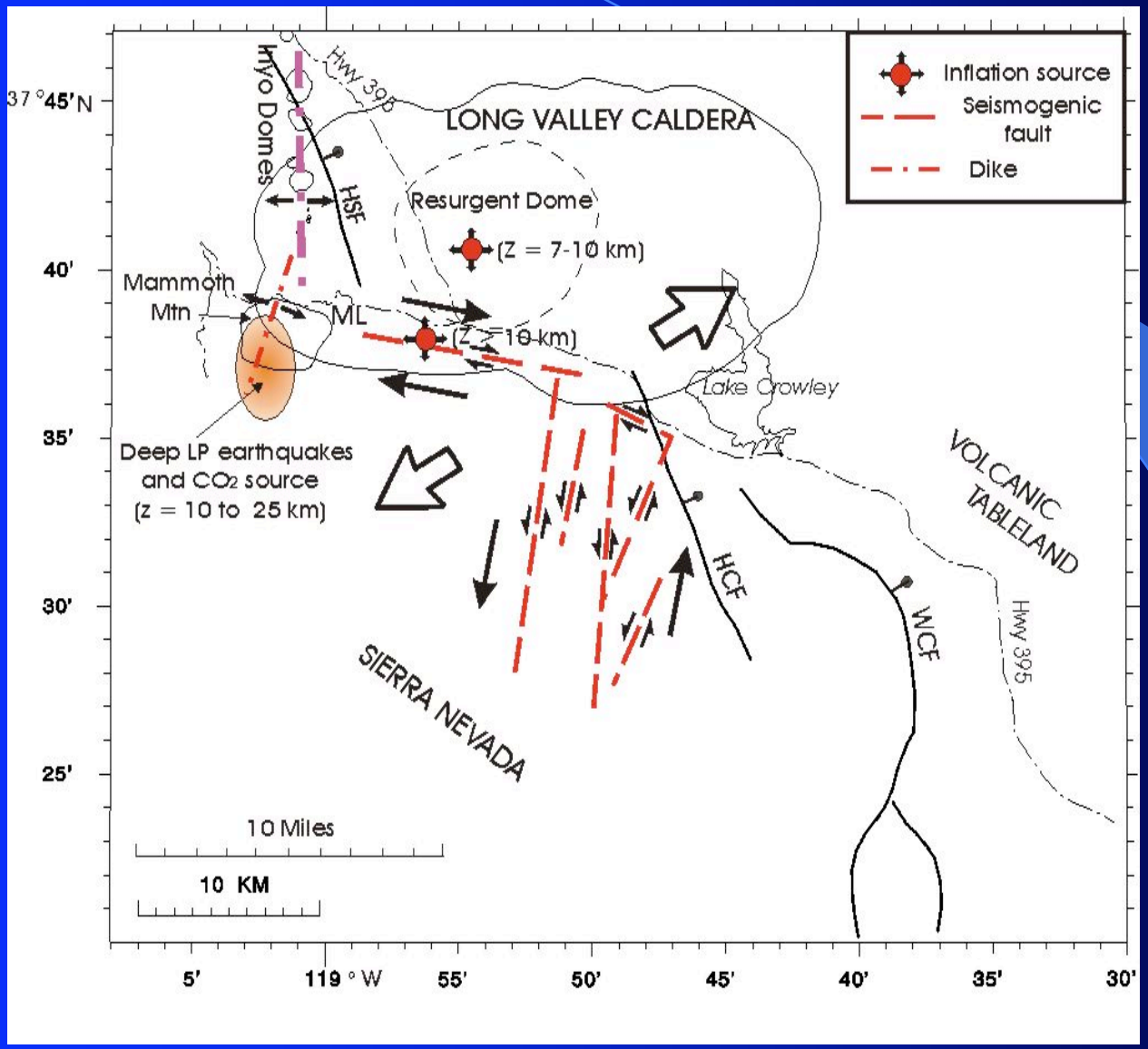
Mammoth Mountain: May 1989 - Jan 1990
(7 months)



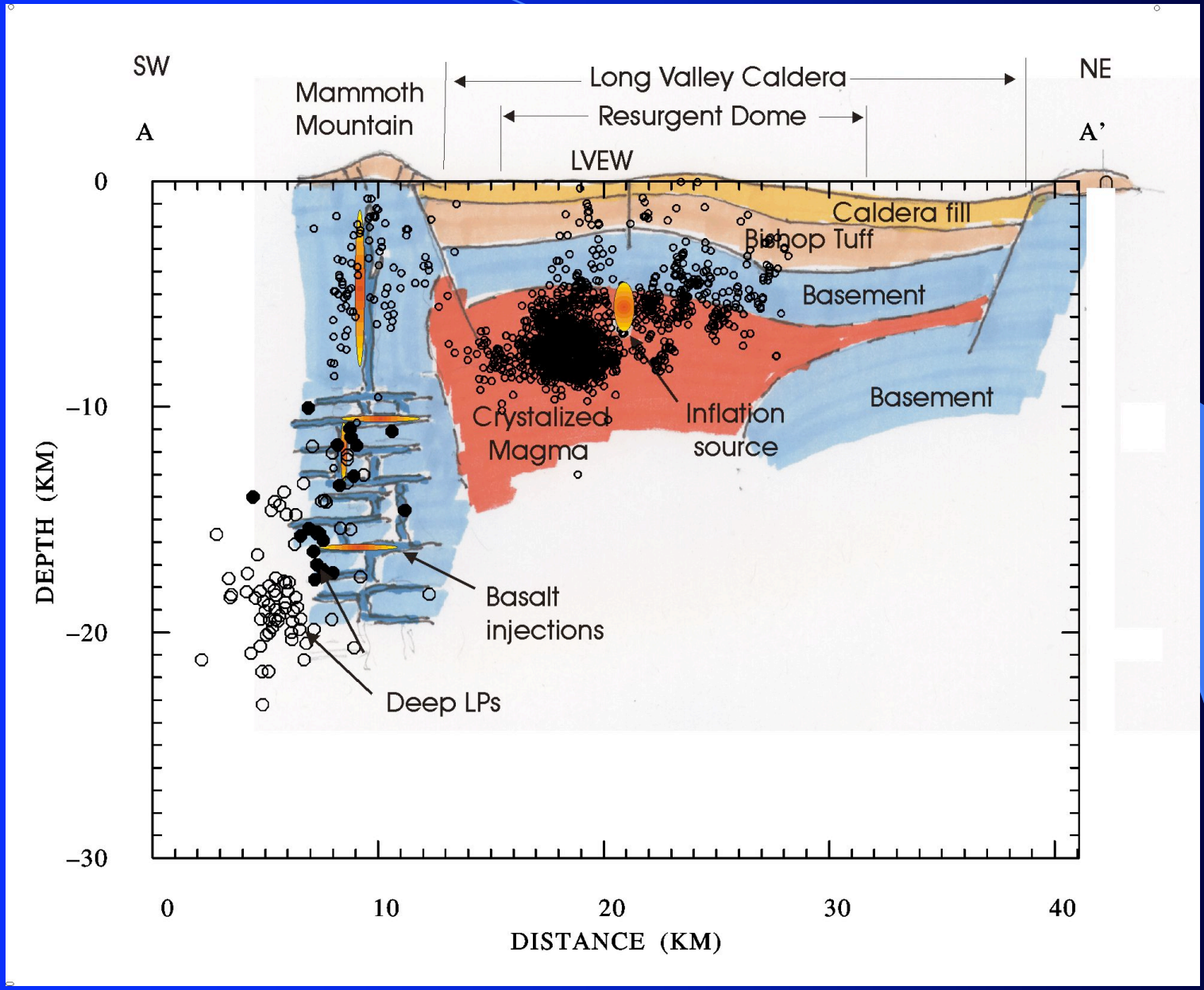
South Moat: November 22-23 1997
(2 days)



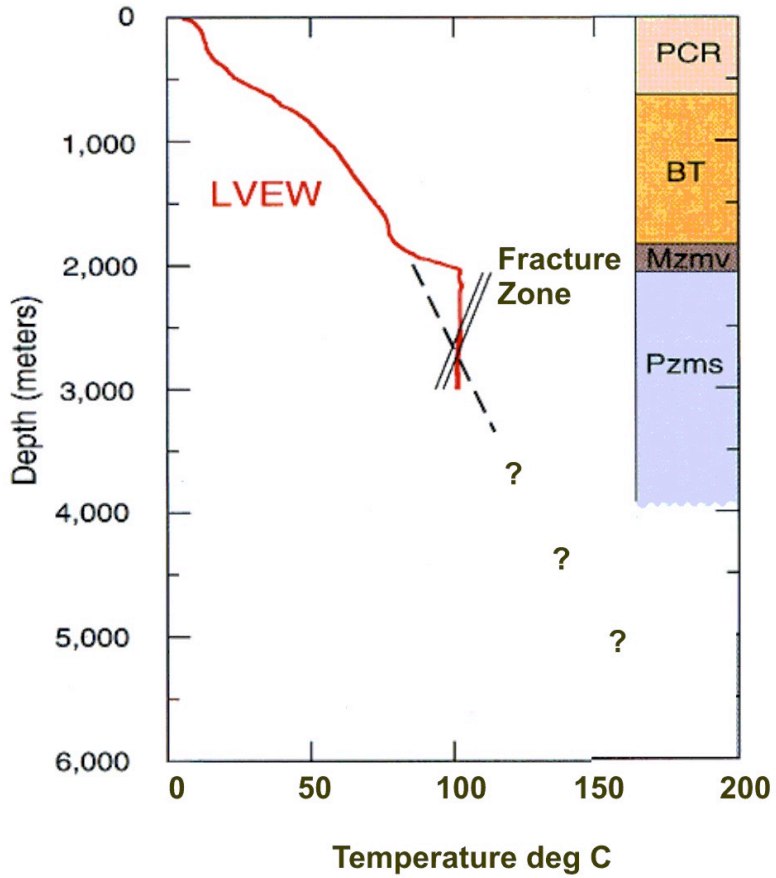
Seismic and deformation sources in LVC

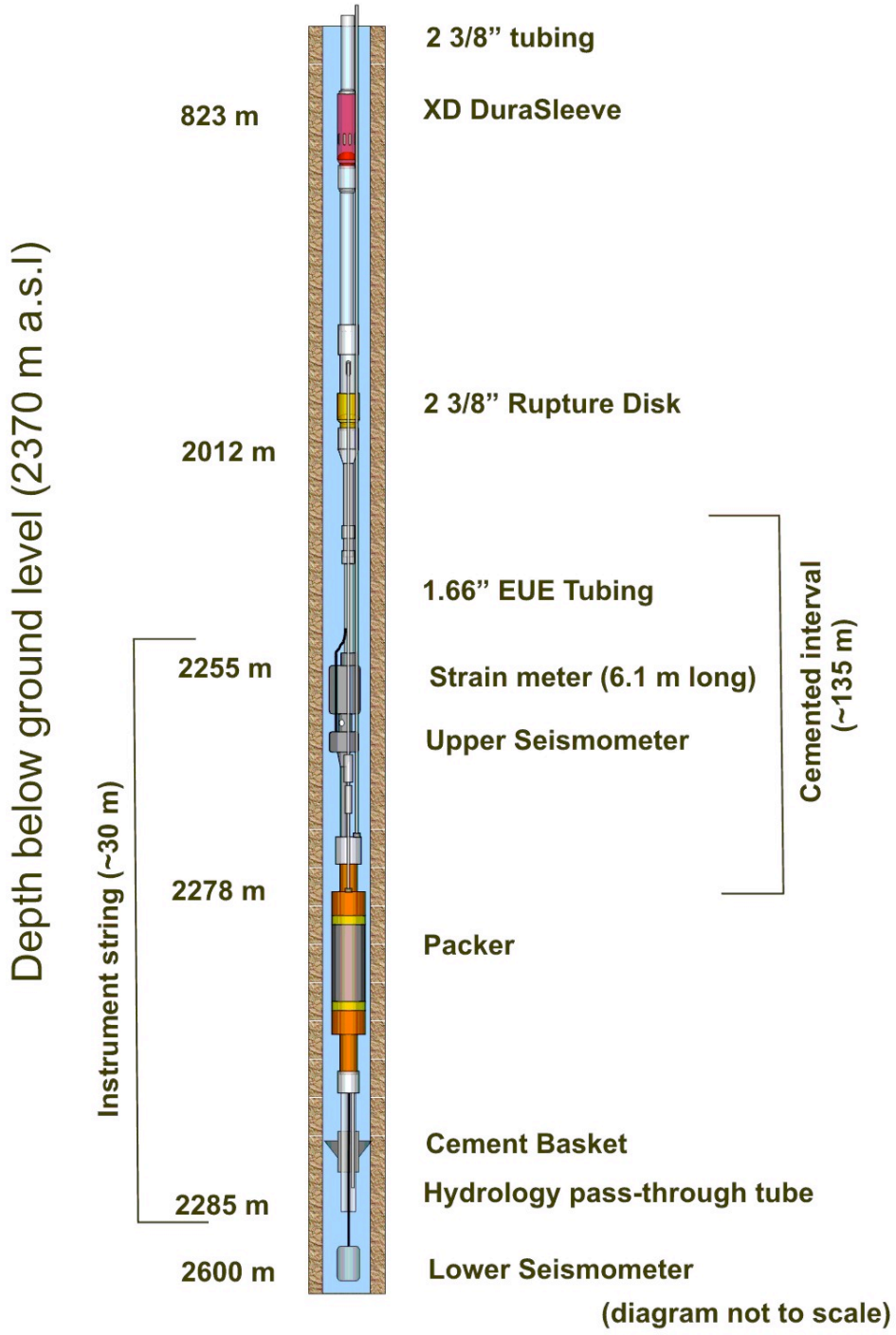


Long Valley Caldera cross-section



LVEW temp, lithology and instrumentation

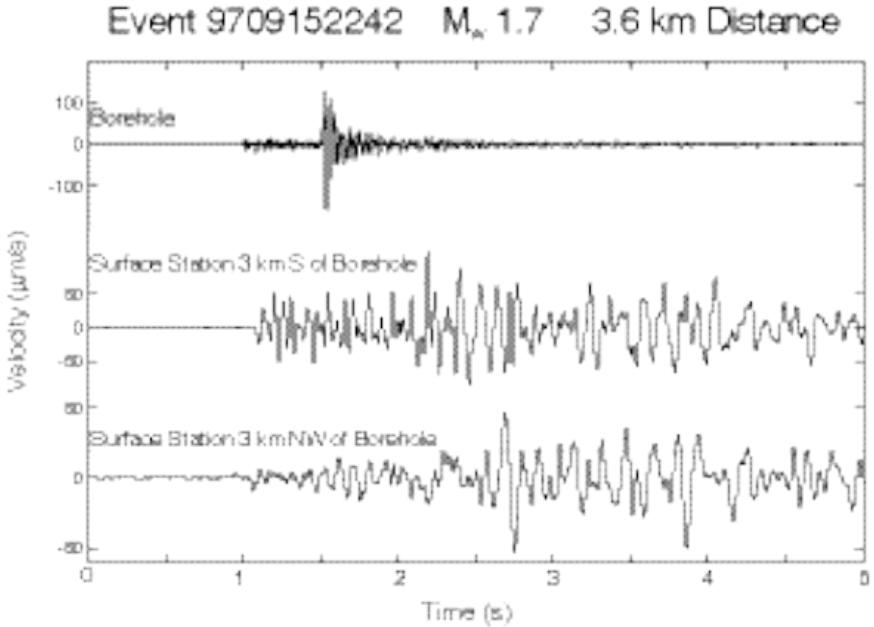


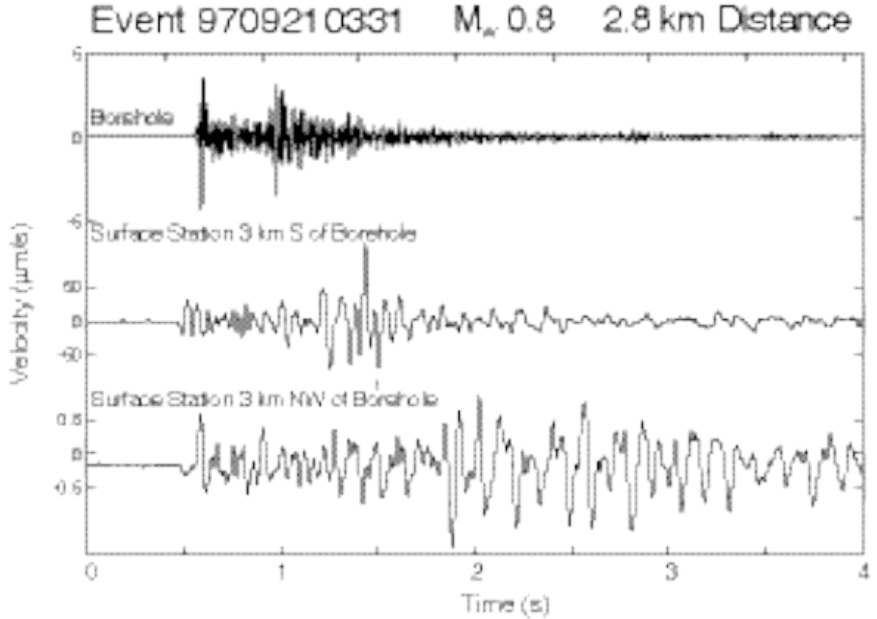


Installing the LVEW instrument string: August 2003

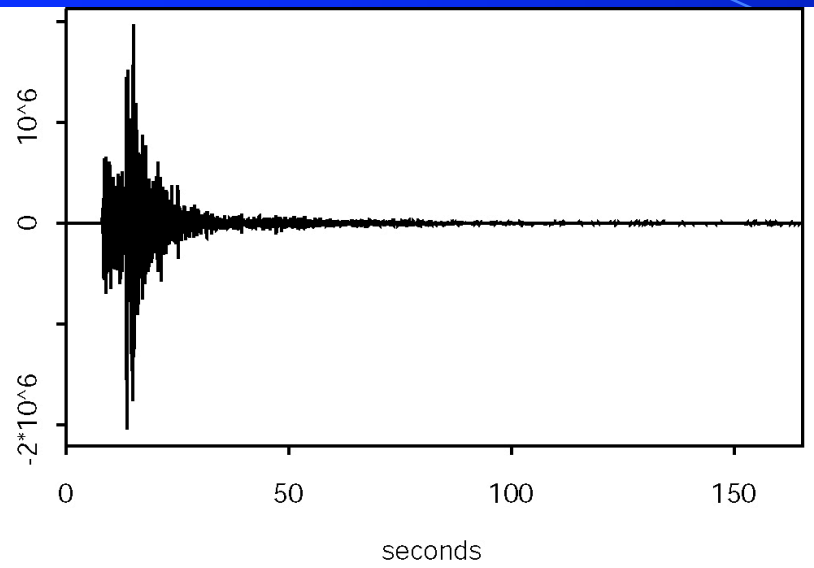
LVEW seismograms from two local earthquakes

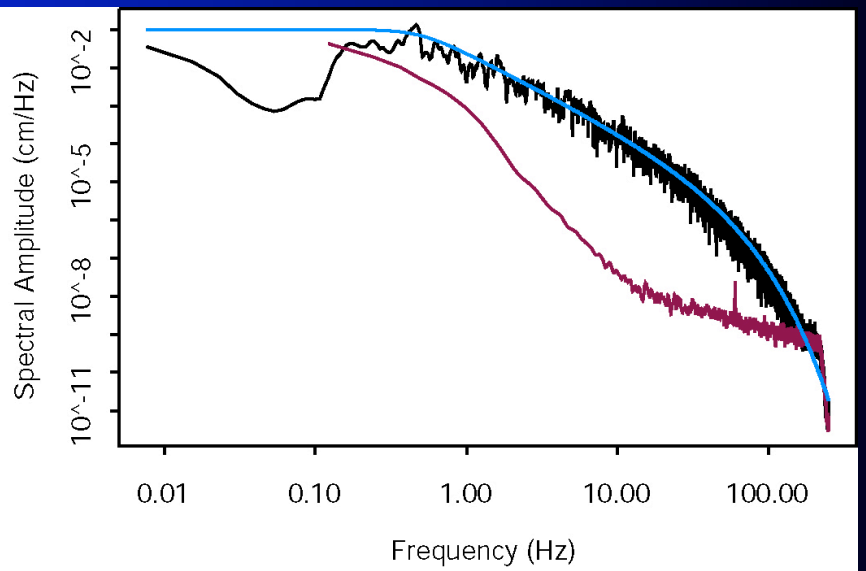
top: LVEW down-hole seismometer
middle: surface seismometer 3 km S of borehole
bottom: surface seismometer 3 km NW of borehole

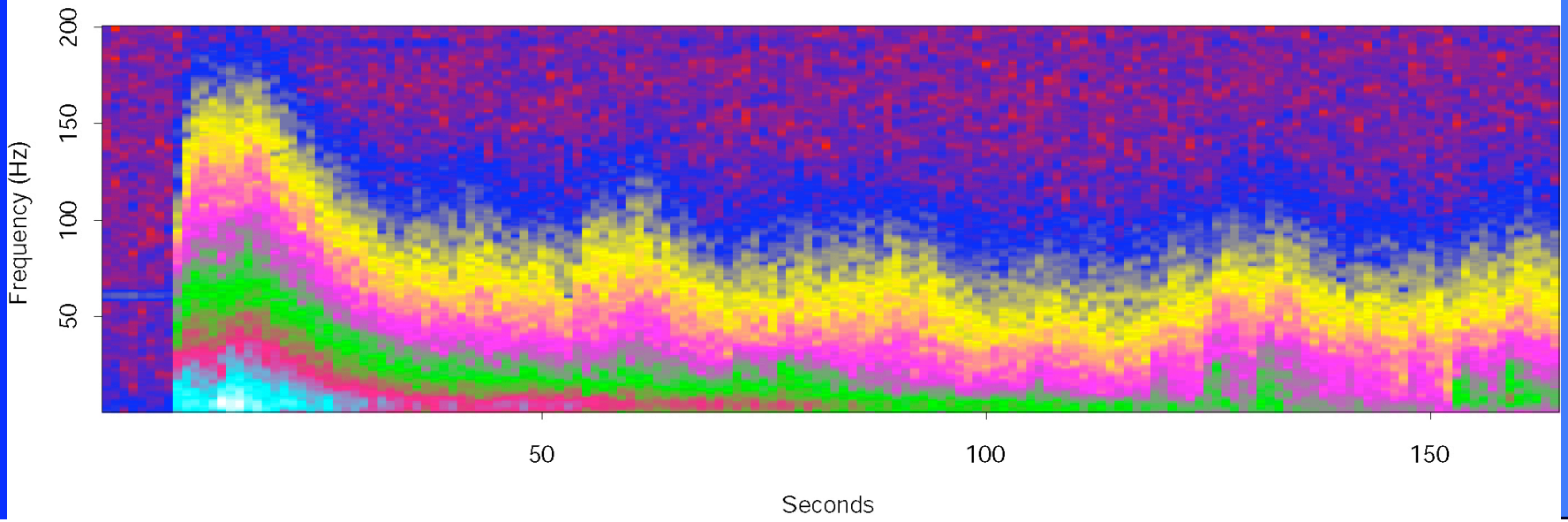




M=5.5 earthquake, Δ=48 km from LVEW lower seismometer







Sunrise on Mammoth Mountain